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Defence Research Establishment Atlantic

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Approved by W. C..E. Nethercote H / Hydronautics Section

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ABSTRACT

The SHOP5 System is a computer-aided ship design tool for monohull frigate and destroyer Concept Exploration. Its primary application is initializing the new-ship design process by determining the ship size, hull form and major systems best suited for the design requirements. Other uses include evaluating new technologies and performing specific parametric studies. The SHOP5 System incorporates three FORTRAN programs in a closed-loop system: program FIVPRE for defining and modifying ship descriptions and design requirements; program SHOP5 for computing ship characteristics; and program FIVPOS for examining design candidates using computer graphics. Design calculations include seakeeping in head seas, resistance, powering and range in calm water and in waves, propulsion and electrical system modeling, distribution of weight and volume components, preliminary intact and damaged stability analysis, and platform acquisition cost. Platform feasibility is assessed by user-definable design criteria which define goals for performance and capability. The SHOP5 ship description and design methodology are sufficiently flexible to define and analyse a wide variety of ship geometries, systems and missions.

RÉSUMÉ

Le système SHOP5 est un outil de conception assistée par ordinateur permettant de concevoir des modèles de frégates et destroyers monocoques. Son utilité principale consiste à amorcer le processus de conception en déterminant la taille du bâteau, la forme de la coque et les principaux systèmes qui conviennent le mieux en fonction des exigences. Le système sert aussi à évaluer les nouvelles technologies et à réaliser l'analyse de certains paramètres particuliers. Le système SHOP5 est constituté de trois programmes FORTRAN qui font partie d'une boucle: le programme FIVPRE sert à définer et à modifier les descriptions et les exigences de calcul; le programme SHOP5 sert à determiner les characteristiques d'un navire; et le programme FIVPOS sert à évaluer les candidats en conception au moyen de l'infographie. Les calculs de conception tiennent compte de facteurs comme la tenue en mer houleuse, la résistance, le démarrage et le rangement en eaux calmes et dans les vagues, la modélisation de la propulsion et du système électrique, la distribution du poids et du volume des composants, l'analyse préliminiare de la stabilité en état intact ou endommagé et le coût d'acquisition de la plate-forme. La faisabilité de la plate-forme est analysée à partir de critères de calcul que l'utilisateur peut choisir et qui définissent les buts en termes de performance et de capacité. La méthodologie de description et de calcul de SHOP5 est suffisamment souple pour définir et analyser une vaste gamme de géométries de bateaux, de systèmes et de missions.

Contents

NOTATION

Names in `typewriter` font and in square brackets, [...], define lineprinter notation.

AccHi	RMS vertical acceleration for zero percent crew effectiveness
AccLo	RMS vertical acceleration for one-hundred percent crew effectiveness
AccMax	seakeeping criterion, maximum vertical acceleration at station 4, $\ddot{z}_{max}$
AK	cost factor
AP	after perpendicular $\equiv$ station 20
A_M	midship sectional area
avPgen	average ship service electrical power generated
A_W	waterplane area
B	maximum beam [B]
C	compartment standard of flooding (for damaged stability)
Ca	model-ship correlation allowance (resistance)
C_{App}	coefficient of appendage resistance, $C_{App} = R_{App}/\frac{1}{2}\rho S V^2$ [Capp]
C_B	block coefficient, $C_B = \nabla/L\,B\,T$ [Cb]
C_M	midship section coefficient, $C_M = A_M/B\,T = C_B/C_P$
CODAD	engine configuration; combined diesel and diesel
CODAG	engine configuration; combined diesel and gas turbine
CODOG	engine configuration; combined diesel or gas turbine
COGAG	engine configuration; combined gas turbine and gas turbine
COGOG	engine configuration; combined gas turbine or gas turbine
C_P	prismatic coefficient, $C_P = \nabla/A_M L$ [Cp]
CPP	controllable pitch propeller
CrM	Froude length/displacement ratio, Ⓜ $= L/\nabla^{\frac{1}{3}}$
C_W	waterplane coefficient, $C_W = A_W/L\,B$ [Cw]
DIAM	propeller diameter
D	midship hull depth [D]
DENS	hull material density, ρ_{hull}
DISP	full load displacement, Δ
Dstruc	structural hull depth (keel to strength deck)
dP_E	design margin on effective power, $P_E = P_E(1 + dP_E)$ [dPe]
dWi	margin for weight component i

dWb	margin on W_{basic}, used for future growth margin
dVi	margin for volume component i
dVhull	special parameter for reducing SHOP5 estimate of hull volume
e	transport effectiveness $e = W_{combat}/\Delta\,\Pi$
e_{crew}	crew seakeeping effectiveness
$e_{crew(min)}$	seakeeping criterion, minimum e_{crew} [EffMin]
EffMin	seakeeping criterion, minimum e_{crew}
Ffp	freeboard at forward perpendicular
Fmod	factor on midship sectional modulus
F_{RB}	minimum midship freeboard for reserve buoyancy
F_{slam}	most probable maximum slam force
$F_{slam(max)}$	seakeeping criterion, maximum F_{slam} [SlmMax]
g	gravitational acceleration, 9.807 m/sec^2 (32.174 ft/sec^2)
$\overline{GM}$	metacentric height (solid) [GM]
g.t.	gas turbine
H_W	significant waveheight, seakeeping [Hw]
Hw(r)	significant waveheight, powering and range
IGEN	MCI for ship service electrical generators
IAPPND	MCI for appendage resistance calculations
ICOST	MCI for cost factors
IENGIN	MCI for propulsion system configuration
IPROP	MCI for type of propeller
IRESID	MCI for residuary resistance databases
ISTRUC	MCI for structural materials
IVOLUM	MCI for sizing superstructure
ITTC	International Towing Tank Conference
$\overline{KG}$	vertical centre of gravity
KGb	$\overline{KG}$ for dWb
KGc	$\overline{KG}$ for Wcombat
$\overline{KG}_{max}$	design criterion, maximum intact $\overline{KG}$ [KGmax]
L	ship length between perpendiculars [L]
LCB	longitudinal centre of buoyancy

`LCF`	longitudinal centre of flotation
`Lbulk`	average bulkhead spacing
`Ldamage`	damaged length (percent of L open to flooding)
`Lsuper`	superstructure length (on upper deck)
Ⓜ	Froude length/displacement ratio, Ⓜ $= L/\nabla^{\frac{1}{3}}$ `[CrM]`
MCI	method control integer (see Table 2)
N	complement (number of accomodations) `[N]`
NPL	National Physical Laboratory (UK)
NRC FSS	National Research Council Fast Surface Ship (model series)
`Nbulk`	number of watertight bulkheads
`Ndeck`	number of internal decks
`Ngen`	number of ship service electrical generator sets
`Nshaft`	number of propeller shafts
N_{wet}	number of deck wetnesses per hour
$N_{wet(max)}$	seakeeping criterion, maximum N_{wet} `[WetMax]`
`OPC`	overall propulsive coefficient, $OPC = \eta_m \eta_h \eta_o$
P_E	effective power, $P_E = R_T\, V(1 + dP_E)$
`Pgen`	total installed ship service electrical generation power
P_i	installed power for an individual engine
P_I	total installed propulsion system power `[Pins]`
RMS	root mean square
R_{App}	appendage resistance
R_T	total resistance
R_{V_e}	design criterion, minimum range at V_E `[R(Ve)]`
S	wetted surface area
SFC	specific fuel consumption
`SFCo`	SFC at full power for an individual engine
`SFCg`	SFC of generators
`SFCr`	SFC for rubber engines
`SlmMax`	seakeeping criterion, maximum F_{slam}
`SP`	specific power $\Pi = R_T/\Delta\, OPC$
`spW2`	specific weight of entire propulsion system, `spW2 = W2/Pins`

spW2b	specific weight of propulsion system not including engines, spW2b = (W2 - (W2a)Nshaft)/Pins
spW3	specific weight of electrical systems, spW3 = W3/Pgen
SSPA	Swedish State Shipbuilding Experimental Tank
SSdens	superstructure material density, ρ_{super}
SSthck	average thickness of superstructure material, t_{1c} in Reference [1]
T	midship draft [T]
Tc	mission definition, relative time at V_C
Td	mission definition, relative time at V_D
Te	mission definition, relative time at V_E
T_o	wave modal period, seakeeping [To]
$T_{o(R)}$	wave modal period, powering and range [To(r)]
V	arbitrary ship speed
V_C	cruise speed (design requirement) [Vc]
V_{combat}	combat system volume [Vcombat]
$V_{c(min)}$	design criterion, minimum combat system volume [Vcombat]
V_D	design speed (design requirement) [Vd]
V_E	endurance speed (design requirement) [Ve]
V_f	fuel volume (tankage)
V_{hull}	volume enclosed by hull, $V_{hull} = V_{total} - V_{super}$
V_m	machinery volume
V_{MAX}	maximum calm water speed using installed power [Vmax]
$V_{MAX(W)}$	maximum speed in waves ($H_{W(R)}$) using installed power, not subject to seakeeping criteria [Vmax(w)]
V_n	personnel volume [Vn]
V_o	systems and outfit volume [Vo]
V_{super}	superstructure volume [Vsuper]
$V_{s(max)}$	maximum V_{super} [VsMax]
$V_{s(min)}$	minimum V_{super} [VsMin]
V_{total}	total enclosed volume [Vt]
V_W	seakeeping speed [Vw]
W_{basic}	basic ship weight, $W_{basic} = W_1 + W_2 + W_3 + W_5 + W_6$
W_{combat}	combat systems weight [Wc]

W_d	disposable loads weight [Wd]
WetMax	seakeeping criterion, maximum N_{wet}
W_f	fuel weight $W_f = \Delta - (W_{basic} + W_{combat} + W_d)$ [Wf]
W_1	structure weight [W1]
W_2	propulsion system weight, $W_2 = W_{2a} + W_{2b}$ [W2]
W_{2a}	weight of propulsion engines, includes acoustic isolation module [W2a]
W_{2b}	weight of gearing, shafting, intakes and exhaust, etc. [W2b]
W_3	ship service electrical system weight [W3]
W_5	auxiliary systems weight [W5]
W_6	outfit and furnishings weight [W6]
YIELD	hull material yield strength, σ_{yield}
$\ddot{z}_{max}$	maximum RMS vertical acceleration at station 4 [AccMax]
$	platform acquisition cost
Δ	full load displacement [DISP]
η_h	qualified hull efficiency, $\eta_h = \eta_r(1-t)/(1-w)$
η_m	machinery efficiency
η_r	relative rotative efficiency
η_o	propeller open water efficiency
∇	displaced volume, $\nabla = \Delta/\rho$
Π	specific power $\Pi = R_T/\Delta\, OPC$ [SP]
σ_{yield}	hull material yield strength [YIELD]
ρ	water density
ρ_{hull}	hull material density [DENS]
ρ_{super}	superstructure material density [SSdens]

1 Introduction

The SHOP5 System is a computer-aided ship design tool for monohull frigate and destroyer Concept Exploration. Its primary application is initializing the new-ship design process by determining the size, hull form and major systems of the ship or ships best suited for a particular mission. Other applications include evaluating the effects of new technologies and design requirements on ship characteristics, and performing parametric or comparative studies of a more specific nature.

The SHOP5 System consists of three FORTRAN programs which are arranged to allow rapid definition and analysis of many possible design candidates. Program FIVPRE is an interactive pre-processor for defining and modifying input, program SHOP5 is a stand-alone (batch) program for analysing the ship or ships defined by FIVPRE, and program FIVPOS is an interactive graphics post-processor for comparing design candidates generated by SHOP5.

SHOP5 calculates a variety of ship characteristics, including: deck wetness, vertical accelerations and slam force in head seas; resistance, powering and range in calm water and waves; propulsion and ship service electrical generation systems modeling and performance; ship weight and volume components; intact and damaged stability; and platform acquisition cost. The platform acquisition cost does not include any combat system or life-cycle costs, and is not sufficiently detailed for budgetary purposes; however, it is a useful, comparative parameter for performing design trade-offs. Platform feasibility is assessed by comparing ship characteristics with a variety of user-definable design requirements and criteria, including: combat system weight and volume; operational speeds and range; acceptable limits for seakeeping response parameters; and other criteria for structural integrity and static stability.

The SHOP5 ship description and design methodology are sufficiently flexible to define and analyse a wide variety of ship geometries, systems and missions. Most input parameters have pre-programmed, default values representative of contemporary NATO practice, and a variety of internal methods are available for many design calculations. All default values and most calculations can be modified or replaced by user-supplied input. Thus, the SHOP5 user should be familiar with the options for program input and have sufficient knowledge of the SHOP5 methodology to determine when default values and methods should be replaced by user-supplied input.

This Technical Communication describes the SHOP5 System operation, input and output. A brief summary of the traditional and contemporary design processes highlights some key problems which are overcome by the SHOP5 System, without sacrificing the desirable aspects of traditional design. The SHOP5 System structure and modes of operation are discussed and all input parameters are described. An overview of the SHOP5 design methodology summarizes important topics, including: the methods used to obtain a "balanced" ship; the dependence of SHOP5 calculations on contemporary practice; the comparative nature of the SHOP5 platform acquisition cost; and, the definition and usage of design margins. The SHOP5 System output structure is described, with emphasis on features for reducing the amount of program output which must be examined. Finally, the primary application for the SHOP5 System is illustrated by an example of design optimization, followed by a

brief discussion of other applications. The SHOP5 System technology base is documented in Reference 1.

2 Concept Exploration: Traditional vs Contemporary

The traditional design process can be illustrated as a spiral, as shown in Figure 1 [2][1]. The process begins by selecting a "basis ship", which is an existing ship whose capabilities closely match those required for the new design. The design progresses through three conceptual phases: Exploration, Development and Validation. Each phase considers the same general aspects of design, illustrated by the radial components in Figure 1, but the transition between design phases represents an increase in the level of detail and accuracy of both the ship description and design analysis. The primary goal of Concept Exploration is to initialize Concept Development by determining the ship size, hull form and major systems required to satisfy the design requirements. The end-product of this preliminary design process is the contract design, which defines the ship in sufficient detail to accurately estimate acquisition and operating costs, and to develop construction plans.

In the traditional context, the Concept Exploration phase is used to obtain the best variant of the basis ship for the current design requirements. This approach has a number of significant advantages: it has produced a long history of successful designs; it permits very rapid transition to the Concept Development phase; and it generally produces new designs whose performance is at least as good as the basis ship. On the other hand, there are significant problems associated with this process: it is often difficult to select an appropriate basis ship, especially when new systems or requirements are considered; there is no assurance of an "optimum" or "cost-effective" result, as the selection of a basis ship narrows the field of design possibilities at the very start of the design process; and, it constrains innovation.

The Concept Exploration Model (CEM), first reported in Reference 2, offers a solution to the problems associated with the traditional design process, while retaining its advantages. A CEM is a computer-based design tool which assists the naval architect in the earliest phase of ship design. A CEM separates the general design process into two functional stages; design synthesis and design analysis. Design synthesis is performed by the naval architect in defining ship geometry and systems for input to the CEM, and design analysis is performed by the CEM.

When using a CEM, the contemporary design process is essentially the same as the traditional process, with one major difference; the requirement to select a basis ship to initiate the process is eliminated. This does not mean that the capability to use a basis ship has been removed, rather, it is not required. The methods used by a CEM are sufficiently general to consider a wide range of design options, with reasonable confidence in the results. Since a basis ship is not required, the designer can consider a much larger field of possible design candidates, and since a CEM is a flexible design tool, the designer can employ a wide variety of contemporary, new, and anticipated future technologies. Also, a CEM can easily model existing ships, for direct comparison of new design candidates with established performance.

[1] numerals enclosed in square brackets denote references

The basis ship still plays an important role in contemporary design. The characteristics of existing ships provide valuable guidance for defining initial CEM input, and many of the details required for the Concept Development ship description must be based on existing ships. A CEM allows the designer to select the best basis ship for Concept Development or to create a "hybrid" basis ship by combining systems from existing ships. Alternately, a CEM allows the designer to compare and/or combine contemporary and new technologies.

Another important difference in Concept Exploration between the traditional and contemporary design processes is the relative importance of seakeeping analysis. In the traditional process, seakeeping is the last step of design analysis, while in a CEM, seakeeping analysis is the first step after defining ship geometry. Of course, reliable seakeeping analysis methods have only been available for a relatively short time, but when first introduced, they were not given high priority. Thus, although the capability for meaningful seakeeping analysis has existed, it has not been an integral part of the design process. The shift in emphasis of seakeeping analysis is due to the realization that ships optimized for calm water performance often do not perform adequately in the typical, open-ocean environment.

The final difference between traditional and contemporary design considered here is the recent introduction of new platform types, including: SWATH ships; hydrofoils; Surface Effect Ships (SES); and, Air Cushion Vehicles (ACV). The Concept Exploration phase now has two major functions: first, to determine the platform type best suited to the design requirements; and then, to determine the ship size, hull form and major systems for input to the Concept Development phase. The traditional design process, with its dependence on a basis ship, cannot easily cope with different platform types. Indeed, using the traditional design process for new platform types forces the designer to enter the Concept Development level of design detail before a reasonable number of alternatives can be explored. For contemporary design, the CEM must be either sufficiently flexible to model all relevant platform types, or there must be more than one kind of CEM. At DREA, the latter approach has been used, resulting in a family of CEM's for different platform types, including; SWATH [3], hydrofoil [4], and SES/ACV [5].

3 Overview of the SHOP5 System

The name SHOP5 stands for "SHip OPtimization, version 5"; however, it is important to appreciate that SHOP5 has no in-built optimization procedures. The design logic used in SHOP5 is relatively simple; given ship size, hull form, major systems and design requirements, SHOP5 calculates performance and capability. Optimization is an iterative and comparative process controlled by the user, as described in following sections.

3.1 Integrated SHOP5 System

The SHOP5 System is arranged to permit the rapid definition, analysis and inspection of many possible design candidates. A schematic view of the three SHOP5 System components is shown in Figure 2, where:

- FIVPRE is an interactive pre-processor for defining and modifying ship descriptions and design requirements for input to SHOP5;

- SHOP5 is a stand-alone (batch) program for analysing the ships defined by FIVPRE; and

- FIVPOS is an interactive graphics post-processor for inspecting ships output from SHOP5.

These three components are integrated into a closed-loop, user-friendly system which allows the designer to define ship descriptions, analyse their characteristics, inspect feasible design candidates, and then create new ship descriptions based on previous results.

3.2 Modes of Operation

SHOP5 has two modes of operation; SEARCH and DESCRIBE. The SEARCH mode allows the designer to define up to 800 ships for a single execution of SHOP5. As SHOP5 proceeds through its design calculations (analagous to traveling around the design spiral), the characteristics of each ship are compared with the design requirements and other criteria, and ships which do not satisfy these constraints are rejected. The characteristics of feasible ships are transferred to FIVPOS, where the designer uses computer graphics to inspect and compare the design candidates.

The DESCRIBE mode is different from the SEARCH mode in three respects: it only considers up to 11 individual ships; it does not reject ships; and it performs more detailed calculations for some design steps. The DESCRIBE mode is used to to obtain more detailed output for individual ships and to model existing ships for comparison with design candidates generated by SHOP5. Also, it may be used to examine ships rejected in the SEARCH mode.

The term "closed-loop system" refers to the data flow from program FIVPOS to program FIVPRE. When using FIVPOS to examine design candidates generated by SHOP5 in the SEARCH mode, the user can select up to eleven ships for transfer to FIVPRE, where they are automatically inserted in a new DESCRIBE mode file. The user can immediately run SHOP5 using this file or, more often, use this file as a basis for a new SEARCH mode file.

4 SHOP5 Input

SHOP5 input consists of the ship description, design requirements, design criteria, and controls for design methodology. The ship description defines ship size, hull form, topside geometry, and major systems. The design requirements define the combat system and operational speeds, and for the SEARCH mode, the design criteria define goals for performance and capability. The controls for design methodology allow the designer to select options for the method used for particular design calculations, and to configure major ship systems.

With the SHOP5 System, program FIVPRE [6] is used to define all input. FIVPRE can be used in either a menu- or command-driven mode, and provides a comprehensive on-line help facility. The example on design optimization presented in Section 7 describes many of the features available in FIVPRE.

Table 1: Typical SEARCH Mode Variation of Required Input

Parameter	Low Value	High Value	Number of Values	(increment)
Δ (tonne)	3000.00	4000.00	6	200.00
Ⓜ	7.50	8.50	3	0.50
C_P	0.58	0.62	3	0.02
C_B	0.48	0.52	3	0.02
B/T	2.80	3.10	4	0.10

The remainder of this section describes the parameters used in the ship description, design requirements, design criteria, and controls for design methodology. A detailed summary of the SHOP5 input record structure is presented in Appendix A.

4.1 Ship Description

For input purposes, the ship description is divided into three categories; required input, optional input and method control integers. The required input consists of the following five parameters, which define ship size and underwater hull form.

1. Characteristic dimension, which can be either
   - full load displacement, Δ (tonne:ton)
   - length, L (m:ft)
   - beam, B (m:ft), or
   - draft, T (m:ft)
2. Froude length/displacement ratio, Ⓜ $= L/\nabla^{1/3}$
3. Prismatic coefficient, $C_P = \nabla / L\, A_M$
4. Block coefficient, $C_B = \nabla / L\, B\, T$, and
5. Beam/draft ratio, B/T.

In the DESCRIBE mode, each ship has explicit values for these parameters, and in the SEARCH mode, each parameter is defined as a range (i.e. low value, high value and number of values). For example, Table 1 defines 648 possible design candidates for the SEARCH mode.

4.1.1 Optional Input

The optional input parameters provide single-value definitions for a variety of geometric, system and design parameters, including design margins. Each optional input parameter has

a pre-programmed, default value or method which is representative of contemporary NATO practice. The designer can define replacement values for any or all of these parameters; otherwise, the defaults are used. Appendix B describes these optional input parameters, including their default values and options for user-supplied input. Details on the algorithms for calculating the optional input default values are provided in Reference 1.

Program FIVPRE allows the user to access each optional input parameter individually (command mode), or via a multi-level menu system.

4.1.2 Method Control Integers, MCI

The method control integers (MCI) control options for the SHOP5 design methodology and configure major systems or arrangement parameters, as shown in Table 2. The MCI's are similar to the optional input parameters, except they define items which have a substantial impact on the design methodology. Also, most MCI's accept variable amounts of user-supplied input to replace their default methods. In Table 2, the SHOP5 default methods are shown for values of 0 (zero), which are used unless explicitly redefined by user-supplied input. Program FIVPRE allows the user to change the MCI values individually or via a menu system. Five MCI's are directly associated with the ship description; ISTRUC, IPROP, IENGIN, IGEN, and IVOLUM. The applicability of the other MCI's for residuary resistance, appendage resistance and cost factors must be evaluated in terms of the ship description. Reference 1 describes the resistance and cost algorithms and defines their requirements for user-defined input.

4.2 Design Requirements

The design requirements are required input which define the following parameters:

- combat system weight, W_{combat}
- design speed, V_D
- cruise speed, V_C
- endurance speed, V_E
- seakeeping speed, V_W
- seakeeping significant wave height, H_W

The combat system weight includes all weapons, sensors, electronics, ammunition and aviation items, including aviation fuel. For new-ship design, the combat system is usually specified as part of the design requirements. When this information is not known, then a suitable value for W_{combat} can be determined by examining existing ships. Alternately, a number of W_{combat} values can be considered, by defining multiple sets of design requirements (different only in W_{combat}) and sequentially generating design candidates for each set of requirements. The combat system volume is considered as a design criterion, as explained in later sections.

Table 2: Method Control Integers, MCI.

NAME	VALUE	DESCRIPTION
IDIMEN Characteristic Dimension	0	full load displacement, Δ (tonne:ton)
	1	length between perpendiculars, L (m:ft)
	2	maximum beam, B (m:ft)
	3	midship draft, T (m:ft)
IRESID Residuary Resistance	0	NRC FSS
	1	Taylor, Hamburg C, or NPL/SSPA
IAPPND Appendage Resistance	0	SHOP5 method (assumed appendages)
	1	user-defined resistance coefficient
IPROP Propulsive Efficiency	0	SHOP5 method, controllable pitch
	1	SHOP5 method, fixed pitch
	2	user-defined OPC values
ISTRUC Structural Material	0	homogeneous
	1	hybrid
IENGIN Propulsion System	0	SHOP5 rubber engines
	1	user-defined rubber engines
	2	SHOP5 real engines
	3	user-defined real engines
IGEN Electrical Generation	0	SHOP5 diesel generators
	1	SHOP5 gas turbine generators
	2	user-defined generators
	3	integrated (propulsion system)
IVOLUM Superstructure Volume	0	$V_{combat} = f(V_{super})$
	1	$V_{super} = f(V_{combat})$
	2	$V_{super} = f(\overline{GM}/B)$
ICOST Cost Factors	0	SHOP5 method
	1	user-defined cost coefficients

The first three ship speeds, V_D, V_C and V_E, are used to calculate resistance, powering and range. Also, the required powers at V_D and V_C are used to select propulsion system components. Note that SHOP5 selects propulsion system components for required power in waves, using a sea state defined by optional input parameters for significant waveheight, $H_{W(R)}$, and wave modal period, $T_{o(R)}$. This significant waveheight has a default value of 3 metres and the default value for $T_{o(R)}$ is calculated for the North Atlantic [1].

The seakeeping speed, V_W, defines the minimum acceptable sustainable speed in waves, which is evaluated by comparing calculated seakeeping responses in deck wetness, vertical accelerations and slam force with user-definable seakeeping criteria, described later. The seakeeping significant waveheight, H_W, together with the seakeeping wave modal period, T_o (an optional input parameter), defines the sea state for seakeeping calculations. The seakeeping speed and waveheight are specified as required input to emphasize their importance to contemporary design.

4.3 Design Criteria

The following design criteria are used to assess platform feasiblility in the SEARCH mode.

- range at endurance speed, R_{V_e}
- number of deck wetnesses per hour, $N_{wet(max)}$
- RMS vertical acceleration/g at station 4 [2], $\ddot{z}_{max}$
- slam force/displacement ratio, $F_{slam(max)}$
- crew seakeeping effectiveness, $e_{crew(min)}$ (percent)
- overall propulsive coefficient, OPC_{min}
- vertical centre of gravity, $\overline{KG}_{max}$ (m:ft)
- combat system volume, $V_{c(min)}$ (m^3:ft^3)

The range at endurance speed must be defined by user-supplied input, and all other design criteria have default values or methods which can be replaced by user-supplied input. As each design candidate progresses through the SEARCH mode design process, it is compared with these criteria; when a criterion is violated, the ship is rejected and the next design candidate is considered. For initial runs in the SEARCH mode, it is not unusual for most or all ships to be rejected for violating design criteria. In this case, it is often useful to temporarily reduce the dominant design criteria values, and examine the less capable ships to identify trends that may suggest a path to acceptable ships.

The range criterion, R_{V_e}, defines the minimum acceptable range at endurance speed, V_E. When more than one range criterion is defined for a particular mission, then R_{V_e} and

[2] The station numbering convention used by SHOP5 has station 0 at the forward perpendicular and station 20 at the after perpendicular.

V_E should model the condition most likely to be dominant, and other range criteria can be rapidly assessed using the computer graphics available in program FIVPOS.

The four seakeeping criteria are used in both the SEARCH and DESCRIBE modes. Their default values are, respectively, 60 deck wetnesses per hour, 0.20 gravities, 0.20 for the slam force/displacement ratio, and 50 percent for crew effectiveness. In the SEARCH mode, the seakeeping behaviour of each design candidate is evaluated for the seakeeping speed and significant waveheight (design requirements), and when a seakeeping criterion is violated, the ship is rejected. In the DESCRIBE mode, SHOP5 calculates the ship speed at which each criterion is violated.

The design criterion OPC_{min} is evaluated at endurance speed, and provides a convenient method for early rejection of ships with very low propulsive efficiency. The default value for OPC_{min} is 0.60 (60 percent).

By default, the design criterion $\overline{KG}_{max}$ is the maximum, intact transverse vertical centre of gravity for positive stability in the damaged condition. This parameter can be redefined by user-supplied input as either a fixed value or as a fraction of midship hull depth (i.e. $\overline{KG}_{max} = 10$ (m) or $\overline{KG}_{max}/D = 0.60$). When a ship's intact $\overline{KG}$ exceeds $\overline{KG}_{max}$, the ship is rejected. Another rejection criterion is the minimum midship freeboard for reserve buoyancy in the damaged condition, F_{RB}. This criterion is not listed above, as it cannot be re-defined by the user. The damaged condition is defined by the standard of compartmentation, C, which is an optional input parameter with a default value of 3 (i.e. three adjacent compartments flooded). This parameter can be redefined by user-supplied input as either the number of compartments flooded or as a fraction of ship length open to flooding.

The minimum acceptable combat system volume, $V_{c(min)}$, has a default value equal to 12.5 percent of total enclosed volume (i.e. $V_{c(min)}/V_{total} = 0.125$). Since this parameter is of major importance and varies dramatically with mission and combat system components, it is recommended that user-supplied input be provided for $V_{c(min)}$ whenever possible.

Finally, three conditions can lead to rejected ships in both the SEARCH and DESCRIBE modes.

- The derived midship coefficient ($C_M = A_M/B\,T = C_B/C_P$) is outside the allowable range for the residuary resistance database.
- The calculated thrust loading coefficient (see Reference 1) is outside the allowable range for the propeller open water database.
- An internal or user-supplied real-engine database cannot produce an adequate propulsion system, which usually indicates that the design speed power requirements exceed the capability of the systems available.

5 Overview of Design Methodology

For each ship, the following calculations are performed sequentially.

- geometry

- seakeeping
- resistance, propulsive efficiency and required power
- propulsion system selection and performance
- ship service electrical generation system performance
- total enclosed volume
- weight components
- range
- stability
- volume components
- platform acquisition cost

The "arrangements" and "structure" design steps shown in Figure 1 are not included above, as they are not considered in sufficient detail to warrant separate status. In SHOP5, arrangements are considered in two stages: the ship description defines geometry and major system configurations; and the weight, volume, and stability algorithms contain empirical relations based on contemporary NATO frigates and destroyers. The key arrangement parameter calculated by SHOP5 is the combat system volume, V_{combat}. This parameter is a measure of the internal space available for combat systems; however, the actual arrangement of spaces is not considered. Similarly, key structural geometries are defined by the ship description, and the algorithm for structural weight, W_1, incorporates criteria for longitudinal strength and minimum material thicknesses; otherwise, structures *per se* are not considered.

5.1 Balancing Weight and Volume Components

One of the most important aspects of the SHOP5 design process is the method used to achieve a "balanced" design. Ship weight components are balanced by the definition of fuel weight, W_f.

$$W_f = \Delta - (W_1 + W_2 + W_3 + W_5 + W_6 + W_d + W_{combat})$$

where Δ is the full load displacement, W_1 is structural weight, W_2 is the propulsion system weight, W_3 is electrical systems weight, W_5 is auxiliary systems weight, W_6 is outfit and furnishings weight, W_d is the disposable loads weight, and W_{combat} is the combat system weight.

The full load displacement is defined by the ship description and combat system weight is defined as a design requirement; the remaining weight components are estimated using empirical methods described in Reference 1. The fuel weight is a major factor in determining range, which is used as a design criterion in the SEARCH mode; any ships with insufficient

range at endurance speed are rejected. SHOP5 estimates W_f for eleven existing NATO frigates and destroyers to within a maximum error of 3.2 percent of displacement (average of 0.2 percent, standard deviation of 2.2 percent). More details are presented in Reference 1, including a tabular summary of estimating errors for all weight components.

Similarly, the balance of volume components is achieved by the definition of combat system volume, V_{combat}.

$$V_{combat} = V_{total} - (V_m + V_o + V_n + V_f)$$

where V_{total} is the total enclosed volume, V_m is machinery volume, V_o is outfit and systems volume, V_n is personnel volume, and V_f is fuel volume.

The total enclosed volume, V_{total}, is defined by the ship description and other volume components are estimated using methods discussed in Reference 1. Thus, the combat system volume is the sum of spaces not required for any other ship functions. In the SEARCH mode, V_{combat} is compared with the user-definable minimum acceptable combat system volume, $V_{c(min)}$; all ships with insufficient V_{combat} are rejected. SHOP5 estimates V_{combat} for eleven existing NATO frigates and destroyers to within a maximum error of 3.2 percent of V_{total} (average of 0.5 percent, standard deviation of 1.9 percent). More details are presented in Reference 1, including a tabular summary of estimating errors for all volume components.

5.2 Defining Total Enclosed Volume

The total enclosed volume is separated into two components, hull volume, V_{hull}, and superstructure volume, V_{super}.

$$V_{total} = V_{hull} + V_{super}$$

For an individual ship, V_{hull} is defined by underwater and topside geometries, and so it is fixed by the ship description; however, there are three options for determining V_{super} (controlled by method control integer IVOLUM, see Table 2).

1. V_{super} is fixed (defined by optional input parameter V_{super})
2. V_{super} is sized to suit a target value for V_{combat}
3. V_{super} is sized to suit a target value for the metacentric height/beam ratio, $\overline{GM}/B$

For the last two options, user-definable minimum and maximum superstructure volumes constrain the variation of V_{super}. In both cases, the minimum superstructure volume serves as a starting point for determining the required V_{super} to satisfy the goal for V_{combat} or $\overline{GM}/B$. In the SEARCH mode, ships are rejected when they cannot satisfy the target value for V_{combat} or $\overline{GM}/B$ within the allowable variation of V_{super}. Reference 1 describes these options in more detail.

The designer must exercise caution when using the SEARCH mode, as SHOP5 only considers volume, not deck area. Since the SHOP5 default method for defining midship

Table 3: Global Limits on Displacement and Hull Form Coefficients

Displacement, Δ:	2000 to 10,000 tonnes
Length/displacement ratio, $\textcircled{M}$:	5.5 to 10.0
Prismatic coefficient, C_P:	0.55 to 0.75
Block coefficient, C_B:	0.35 to 0.65
Beam/draft ratio, B/T:	2.5 to 4.5

hull depth varies with draft and length, it is possible to gain substantial volume through variations in hull depth without significant gains in deck area. It is usually desirable to relate internal volume to deck area by defining a fixed hull depth (see optional input parameter 1 in Appendix B). In this case, variation of internal volume for ships with common hull depth is directly proportional to internal deck area.

The algorithm for estimating V_{hull} assumes a continuous upper deck. In most cases, this is a good assumption but when it is not valid, it is possible to model a discontinuous upper deck, using procedures described in later sections.

5.3 SHOP5 Limits

Table 3 defines the global limits imposed on SHOP5.

Additional constraints on midship sectional area coefficient, C_M, vary according to which method is used for calculating residuary resistance, as described in Reference 1.

The SHOP5 design methodology combines databases derived from model test results and theoretical analyses with empirical equations based on contemporary practice and historical trends. In general, the database approach is used for performance parameters which are primarily dependent on hull form, such as seakeeping and residuary resistance. Ideally, these methods should be used only by interpolation, but the global limits on SHOP5 generally exceed the original limits of the SHOP5 databases. These methods have robust extrapolation procedures which produce reasonable results outside of the original scope of the database; however, validation of these results is difficult due to a lack of data. The SHOP5 user should be familiar with these database algorithms (described in Reference 1) and should use intelligent caution when comparing "radical" hull forms with contemporary practice.

5.4 Dependence on Contemporary Practice

When SHOP5 is used with all defaults for the optional input and method control integers, the resulting ship description is an average of existing NATO practice for such items as hull depth, size and type of appendages and other geometric and system parameters. As the designer replaces SHOP5 defaults with "real" or different data, then the ship description generally follows one of two trends: either converging on the contemporary design practice

of a particular nation, or diverging from existing practice because of new systems or radical geometries.

When the ship description or design requirements are significantly different from contemporary practice, the designer is responsible for determining which SHOP5 methods are applicable and which methods should be replaced or modified by user-supplied input. For example, consider a diesel-electric propulsion system, with the diesel engines located on the highest internal deck level. This system diverges from the SHOP5 defaults in two key areas: its physical characteristics are different in terms of weight, space and performance, and the location of diesel engines high in the hull is a departure from contemporary arrangements practice. This system is best modeled by a user-supplied, real engine database, for which the user defines the type (diesel), available power, specific fuel consumption, and weight of one or more engines. Also, this option accepts user-supplied input to define a propulsion system specific weight and vertical centre of gravity. This specific weight accounts for gearing, shafting and other propulsion system components not included in the engine weight. The weight of the electric motors can be defined as an addition to either the engine weight or the propulsion system specific weight, depending on whether motor weight is fixed or varies with installed power. The absence of significant gearbox weight and shafting is also considered by adjusting the propulsion system specific weight. Other weight differences, such as abnormally heavy foundations or significantly more rafting than normal, should be defined in the appropriate weight margin categories (see Appendix B). The system weight and performance description is completed by selecting a CODAD (COmbined Diesel And Diesel) propulsion system configuration. Next, the designer must determine whether the total space required for this system is different from a contemporary system, as assumed by SHOP5. When significant differences are expected, then the total machinery volume can be defined with the user-supplied propulsion system volume/installed power ratio, V_m/P_I or the SHOP5 volume estimate can be increased using the margin on machinery volume. This system's atypical vertical weight distribution is explicitly modeled with the user-defined propulsion system vertical centre of gravity.

This example illustrates the flexibility of SHOP5 input for modeling non-standard systems, but it also emphasizes that when a new system is used, the designer must have reasonable knowledge of the system characteristics.

5.5 Using Cost as a Comparative Parameter

As stated earlier, the SHOP5 platform acquisition cost is only valid for comparative purposes. This must be qualified further by stating that the SHOP5 default cost factors used to estimate platform acquisition cost (see Reference 1) should only be used for comparing ships with equivalent technology of systems and construction. The default cost factors are derived from historical data with a bias towards recent practice, and these factors are valid for the SHOP5 options which do not require user-supplied input to describe new systems. For example, the relative costs of gas turbine vs diesel engines are considered, but propulsion system cost for the diesel-electric system described above would not be modeled properly. Thus, the platform acquisition cost for diesel-electric ships estimated using default cost factors would be valid for trade-off studies considering only diesel-electric ships, but would not be valid for direct comparison with ships using different propulsion systems.

5.6 Design Margins

When using SHOP5, it is useful to consider four types of design margins: future growth, design and construction (D & C), assurance, and modeling. The first three types are well recognized [7], while the modeling margin is peculiar to SHOP5, as it accounts for items not considered by the SHOP5 algorithms (e.g. extra foundations and rafting for the example diesel-electric system). Future growth margins allow flexibility for refit and modernization programs, or account for items identified for installation but not available in the time-frame of ship acquisition. D & C margins account for uncertainties in the hull form definition and estimating errors or changes to requirements for propulsion, weights, volumes, and stability. Assurance margins are applied to ensure that the ship has adequate capability to meet the design requirements.

SHOP5 defines explict margins for resistance, powering, weights and volumes through the optional input parameters (see Appendix B). Other margins can be implicitly defined by incorporating them in the appropriate input parameters. The recommended procedures for defining margins are discussed in Reference 1, but a few special considerations are discussed here.

Two commonly used assurance margins for the propulsion system are:

1. increasing the required propulsion power to account for the effects of hull fouling and sea state on fuel consumption and range; and,
2. reducing the available engine power to determine maximum sustainable speed.

The first of these margins should never be used with SHOP5; the effects of significant hull fouling should be modeled by adjusting the ship-model correlation allowance, C_A (an optional input parameter), and the effects of sea state are explicitly considered in SHOP5 by calculating the added power in waves. The second margin for determining maximum sustainable speed should be used with caution, as sustainable speed is usually limited by sea state, not power. When this approach must be used, it should be done by defining a user-supplied engine database with engine powers which incorporate the assurance margin. In this case, the design speed (a design requirement) is used as the minimum acceptable sustainable speed.

The SHOP5 range calculations incorporate two assurance margins which cannot be re-defined by the user. These are a five percent reduction in the available fuel weight to account for fuel trapped in tank bottoms and piping systems, and a five percent increase in propulsion system fuel consumption to account for engine degradation in service.

A special note regarding the SHOP5 weight and volume algorithms is necessary, as these algorithms are based on existing, real ship data. Thus, the SHOP5 algorithms include the D & C and assurance margins on weight and volume used for the design and construction of these ships. This does not mean that these weight and volume margins should not be used with SHOP5, but it does indicate that they should be chosen carefully and verified in the Concept Development design phase.

6 SHOP5 Output

This section provides a brief overview of the SHOP5 System output structure. More details are presented later in the example on design optimization and in the appendices. Figure 3 shows the relationship between SHOP5 System input and output. The SHOP5 input prepared using FIVPRE is written to a disk file which is automatically read when SHOP5 is executed. Also, the user can store a copy of the current input in the FIVPRE library for retrieval at a later time. Every time SHOP5 is executed, it produces lineprinter output to summarize all program input, as well as describe the characteristics of feasible ships generated by SHOP5. When the graphical post-processor FIVPOS is used, SHOP5 writes a ship data file on disk, which forms the input for FIVPOS. Every time that FIVPOS is executed, it produces lineprinter output to summarize its input and provide details of the ships rejected by SHOP5. When in FIVPOS, the user can select ships to form the basis for new input to SHOP5 (via FIVPRE), and/or receive lineprinter output describing these ships.

Since the SHOP5 System is used iteratively, the process of generating design candidates can produce a very large amount of lineprinter output; however, the SHOP5 System Program Control menu provides a solution, as follows.

```
 SHOP5 System: Program Control
 -----------------------------
 1.  Run FIVPRE
 2.  Run SHOP5
 3.  Run FIVPOS
 4.  Lineprinter Control
 5.  Editor
 6.  Help
99.  EXIT

Enter NUMBER =>
```

Menu item 4 controls where all lineprinter output is sent; by default, all SHOP5 System lineprinter output is written on a disk file called DATA. The user can re-route this output to the "real" lineprinter by selecting the appropriate option associated with menu item 4. Menu item 5 allows the user to invoke an editor to inspect the contents of DATA. This editor is automatically started by the executive menu system, and requires only four or five simple commands to view all or selected parts of the DATA file. Thus, the great majority of user-program interaction is done at the terminal, and paper output is only used to record milestones in the design process.

Currently, this executive menu is only available for the VAX/VMS operating system (Digital Equipment Corporation), although its functions can be easily duplicated on most computers. This menu provides a convenient environment for using the SHOP5 System, but it is not required. All functions performed by the SHOP5 System, except for the graphics used in FIVPOS, are written in FORTRAN. The SHOP5 System Installation Guide [8] provides details on hardware and software requirements.

7 Design Optimization: An Example

The first steps in using the SHOP5 System are to define the ship description, design requirements and criteria, and determine which SHOP5 methods are appropriate for the current problem. At this stage the key consideration for the ship description is to decide which SHOP5 default parameters are suitable and which should be replaced by user-supplied input. The optimum design candidate is located by an iterative process in which the designer initially considers a wide range of ship sizes and hull forms. The field of possible candidates rapidly narrows, and the designer enters a refinement process in which ship description parameters are varied to assess second-order effects. Often, more than one design candidate appears viable, and so the designer may perform a final selection process in which cost/performance trade-offs determine the optimum candidate. Alternately, it is reasonable to identify more than one design candidate for further examination in the Concept Development phase. This is especially true when the success of a particular design depends on a new and possibly high risk technology. In this case, it is reasonable to have an optimum "advanced" design candidate and an optimum "back-up" candidate using contemporary technologies, just in case the advanced technology is not available or does not perform as expected. Also, the best choice for major ship systems (e.g. engine configuration) or overall arrangements (e.g. relative superstructure size) may not be clear in the Concept Exploration phase. In this case, the designer may not be able to eliminate a particular ship on the basis of Concept Exploration analysis, as key decisions cannot be made until more detailed studies are completed (e.g. noise vs speed or vulnerability vs arrangements).

When using the SHOP5 System, the designer is responsible for all design decisions and for appropriate selection of design candidates. The designer must decide how to configure the ship description and how to modify the SHOP5 methodology, based on personal design experience and particular requirements for the current problem. The SHOP5 default values and methods provide a good starting point, but they must be modified or replaced when they are not suitable.

Major features of the SHOP5 System are now illustrated by an example design problem, which also reflects the iterative and comparative process used for design optimization.

7.1 Design Philosophy

An appropriate design philosophy guides the designer in configuring and selecting design candidates by defining the relative importance of particular ship characteristics. For this exercise, the design philosophy is, in order of precedence, minimize platform acquisition cost, operational costs and technological risk, maximize survivability, minimize detectability, and maximize sustained speed in waves. SHOP5 does not explicitly consider all of these topics, but their relative importance provides valuable guidance for defining and changing the SHOP5 input. Also, the variation of key SHOP5 output parameters provides insight into the relative merits of the design candidates. For example, if combat systems and personnel are fixed, then relative fuel consumption is a fairly accurate measure of relative operational costs.

7.2 Example Design Requirements

The following design requirements and constraints are considered:

- Range in 3 metre waves:
  - 2500 n. miles at 30 knots
  - 4500 n. miles at 20 knots
  - 5000 n. miles at 15 knots
- Combat system weight 375 tonnes
- Combat system volume 2900 m^3
- 50 tonnes weight margin for future growth
- Accomodation spaces of 16 m^3 per person
- Minimum sustainable speed of 20 knots in 5 metre waves, with:
  - maximum of 30 deck wetnesses per hour
  - maximum RMS vertical acceleration of 0.20 gravities, at station 4
  - maximum slam force/displacement of 0.20

7.3 Other Constraints and Decisions

Acceptable intact stability is defined by the metacentric height/beam ratio, $\overline{GM}/B$, with a minimum of 0.095 and of maximum 0.105. Damaged stability is assessed using the SHOP5 method, with the damaged condition defined by 15 percent of length open to flooding. This design uses all-steel construction. An initial midship hull depth of 10 metres will be used for all design candidates, which permits direct comparison of internal space and deck area. This hull depth can be varied to suit individual circumstances, and so it is not truly a design constraint, but it is a convenient assumption which reduces the variations that SHOP5 may consider initially.

The method for estimating complement size will be reduced from the SHOP5 default of $N = \Delta^{2/3}$ to $N = 0.88\Delta^{2/3}$ to model the (arbitrary) contemporary practice of the host navy.

Since the type of propulsion system is not defined by the design requirements, the designer must decide which systems are appropriate. Given the design philosophy stated above, only twin shaft propulsion systems with gas turbine main engines and, when required, diesel or gas turbine cruise engines will be used. Thus, only the following twin-shaft propulsion system configurations will be considered.

- One gas turbine per shaft, with cross-connected gearing
- COGAG (COmbined Gas turbine And Gas turbine)

- COGOG (COmbined Gas turbine Or Gas turbine)
- CODOG (COmbined Diesel Or Gas turbine)

The notation used for combined configurations defines, respectively, the type of cruise engine, type of gearbox ("AND" or "OR") and type of main engine. Since minimizing technological risk is a major consideration for this design, the CODAG configuration is not considered. This omission does not imply that the CODAG configuration is impractical, it simply reflects the fact that no contemporary frigate-sized ships use this type of propulsion system, and so technological risk may be significant.

Ship's service electrical requirements will be provided by four, 1000 kW diesel generator sets.

These requirements and constraints represent the first level of design goals for this platform; further constraints will be enforced and evaluated in later phases of design. This is especially true of constraints associated with the combat system. It is possible to introduce simple constraints such as a minimum acceptable length for arranging on-deck systems, but these cannot be truly evaluated until the internal and external layout (arrangements) are defined, which is usually the second step after using SHOP5 (the first is to define the hull form in more detail).

7.4 Starting the SHOP5 Design Process

For this example, the goal is to identify the most cost-effective design candidate which satisfies all of the design requirements. In order to simplify this task, each type of propulsion system is considered separately, and then the best design candidates for each system are compared.

7.4.1 The First Input File: SEARCH Mode

The immediate task is to define an input file which reflects the design constraints and decisions noted above. The SHOP5 input cannot explicitly model all design constraints defined for this exercise, and so the designer must choose which constraints are pre-set and which are evaluated later (using FIVPOS). For example, three combinations of speed/range requirements are defined, while SHOP5 provides only one design criterion for range. For this exercise, the 4500 nautical mile range at 20 knots is explicitly modeled, and the other two range criterion are assessed when selecting design candidates.

The first input file should define a sufficiently wide variation of ship size and hull form coefficients to produce at least a few feasible design candidates in the SEARCH mode. Once this is accomplished, then the characteristics of these design candidates will guide the designer's selection of subsequent ship size and hull form parameters. The initial variation in ship size and hull form coefficients are shown in Table 4.

The important aspects of this design example are discussed in the following text, but most details are contained in the appendices, as follows. Appendix C shows the first steps in the design process, in which the initial input file is defined for the COGAG propulsion

Table 4: Initial Variation of Displacement and Hull Form Coefficients

Parameter	Low Value	High Value	Number of Values	(increment)
Δ (tonne)	3500.00	4500.00	6	200.00
Ⓜ	7.00	9.00	5	0.50
C_P	0.59	0.59	1	-
C_B	0.49	0.49	1	-
B/T	2.80	3.20	5	0.10

system and subsequently modified to "home-in" on desirable trends observed in FIVPOS graphics. Appendix D shows the final steps in the design process, in which desirable ships have been defined, but a few minor changes are required to satisfy all design requirements. Also, Appendix D contains the FIVPOS and SHOP5 lineprinter output for the COGAG design candidate. Appendix E lists the SHOP5 output parameters that can be examined graphically in FIVPOS.

The initial input file defined in Appendix C defines a total of 44 parameters. An absolute minimum of 29 parameters is required for the SEARCH mode, which includes a title, six program control integers, fifteen parameters to define the variation of size and hull form coefficients (as shown above), and seven mission-definition parameters (speeds, range, etc.). The other 15 parameters are user-supplied input which either replaces a SHOP5 default value (e.g. hull depth = 10 m), or defines a non-default method (e.g. superstructure is sized for the combat system requirements).

This initial input file is defined in a menu-driven mode, using the FIVPRE command "NEW". When this command is given, the user is forced to supply acceptable input for each of the 29 required input parameters, and is provided menus which access all other input parameters. The NEW mode is most useful for creating a new file from scratch; otherwise, the user would modify an existing file by using explicit commands (e.g. change freeboard) and/or by invoking individual, menu-driven procedures (e.g. change optional input). FIVPRE provides abbreviation recognition and ambiguity resolution, as well as complete on-line help.

7.4.2 The First Run

The initial input file defines a total of 150 potential design candidates, but the first execution of SHOP5 indicates that only eight ships satisfy the design requirements that are explicitly modelled. FIVPOS is used to examine these ships and, as shown in Figure 4, none of them satisfy the requirement for 2,500 nautical mile range at design speed (30 knots). Before modifying the initial input to produce ships with greater range at design speed, examining other FIVPOS parameters reveals some interesting trends. Figure 5 shows significant variation in platform acquisition cost corresponding to changes in installed propulsion power. Other FIVPOS graphs shown in Appendix C indicate that superstructure volume and fuel

Table 5: Variation of Parameters For Second SEARCH Mode Input

Parameter	Low Value	High Value	Number of Values	(increment)
Δ (tonne)	4500.00	4500.00	1	-
Ⓜ	8.00	8.50	6	0.10
C_P	0.57	0.61	3	0.02
C_B	0.47	0.51	3	0.02
B/T	2.80	3.2	5	0.10

consumption decrease significantly with increasing Ⓜ. The relatively low-cost design candidates shown in Figure 5 have values of Ⓜ of 7.5, 8.0 and 8.5. Since all of these ships have the same displacement of 4,500 tonnes, this represents a significant variation in length.

7.5 Defining the "Optimum" Design Candidate

In general, after the first few "feasible" ships are generated, the process of identifying "optimum" design candidates is greatly simpified by reducing the range of parameter variations considered at any particular time. In this case, it is useful to consider the relatively short and long hull forms as different potential design solutions, and to examine them independently. The search for a COGAG ship with a relatively long hull form is initiated within FIVPOS by selecting the right-most ship in Figures 4 and 5 (Ⓜ $= 8.5$) for transfer to FIVPRE. When program FIVPRE is executed, a DESCRIBE mode file is automatically produced to model the ship or ships transferred from FIVPOS (if no ships are transferred, then the user can either modify an existing file using ENTER and CHANGE or create a NEW one). In this case, the displacement and hull form coefficients of the transferred ship are: $\Delta = 4500(t)$, Ⓜ $= 8.50, C_P = 0.59, C_B = 0.49$, and $B/T = 3.20$. The DESCRIBE mode file created by FIVPRE for this ship is converted back to the SEARCH mode using a procedure shown in Appendix C and a new set of geometric variations (called the "search space") is defined, as shown in Table 5.

In Table 5, displacement is held constant and finer variations in Ⓜ are used. Also, variations in C_P and C_B are introduced to examine combinations not considered initially. The purpose of this file is to determine which combination of hull form coefficients provides the greatest range at design speed for the relatively long, COGAG ship. Figure 6 shows some of the 105 ships generated by this input file. Ship number 91 has the greatest range at design speed, and so it is used as a basis for subsequent input files which model ships with larger displacements and, hopefully, greater range at design speed.

Figure 7 shows the range at design speed for ships generated later in this example, from which ship number 20 is selected as the optimum design candidate for the long hull, COGAG configuration. Additional information on this ship is contained in Appendix D, including its lineprinter output from both FIVPOS and SHOP5 in the DESCRIBE mode.

The general procedure described above for the long, COGAG ship was repeated for

Table 6: Design Candidates, All Requirements Satisfied

SHIP	A1	B1	C1	D1	E1	F1
Δ (tonne)	4380	4460	4550	4600	4620	4660
N	236	238	242	243	244	246
$	1.00	1.07	0.98	1.05	1.08	1.08
R_{30} (n. mile)	2515	2529	2501	2516	2514	2504
R_{20} (n. mile)	5520	5307	5305	6402	5997	5724
R_{15} (n. mile)	6693	7228	6982	8926	8055	6988
Ⓜ	8.35	8.30	9.05	8.25	8.35	7.65
L (m)	135.5	135.5	148.7	136.1	138.0	126.7
V_{super} (m^3)	2710	2608	2450	2739	3031	4091
$P_{I(main)}$ (kW)	2 x 18650	2 x 18650	2 x 11940	2 x 18650	2 x 18650	2 x 11940
$P_{I(cruise)}$ (kW)	-	2 x 4775	2 x 4775	2 x 5370	2 x 4775	2 x 11940
Configuration	X-connect	COGOG	COGAG	CODOG	COGAG	COGAG
FC_{20} (t/hour)	2.65	2.76	2.70	2.31	2.71	3.12
$V_{MAX(5\,m)}$	23.0	21.1	26.1	21.8	24.6	21.6
$V_{MAX(3\,m)}$	30.2	30.9	30.0	30.1	31.8	30.7

other engine configurations and hull forms, resulting in the six design candidates shown in Table 6. These design candidates are arbitrarily listed in order of increasing displacement, and the relative platform acquisition cost of ship A1 is used to normalize costs for all other ships. The maximum speeds shown at the bottom of this table, $V_{MAX(5\,m)}$ and $V_{MAX(3\,m)}$, are, respectively, the maximum speed in 5 metre waves as limited by the seakeeping criteria and the maximum speed in 3 metre waves as limited by available propulsion power. Note that ship E1 is the long, COGAG design candidate described above and in Appendices C and D. Also, ship F1 is derived from the short, COGAG ships mentioned earlier and shown at the left-hand side of Figures 4 and 5.

At this stage, the designer should be able to select one or two of these design candidates for further definition and analysis in the Concept Development phase. This selection would be based on the relative importance of ship characteristics with respect to the design philosophy and other factors which cannot be assessed by a CEM (e.g. availability of particular engines, compatibility with existing systems, fleet maintenance practice, etc.). This selection is not made here, but a few general observations are made.

These design candidates illustrate that platform acquisition cost does not necessarily

Table 7: Design Candidates, 2000 n. mile Range at 30 knots.

SHIP	A2	B2	C2	D2	E2	F2	A3
Δ (tonne)	4200	4280	4120	4420	4350	4440	4100
N	229	232	226	237	235	238	225
$	1.00	1.07	0.96	1.05	1.07	1.08	0.99
R_{30} (n. mile)	2005	2018	2083	2042	2007	2046	2005
R_{20} (n. mile)	4748	4597	4521	5805	4954	5254	4542
R_{15} (n. mile)	5493	5944	5937	7260	6587	6190	5367
Ⓜ	8.20	8.30	8.85	8.30	8.20	7.50	8.40
L (m)	131.2	133.7	140.7	135.1	132.8	122.3	133.3
V_{super} (m^3)	4153	3625	1805	3773	3381	4752	2996
$P_{I(main)}$ (kW)	2 x 18650	2 x 18650	2 x 11940	2 x 18650	2 x 18650	2 x 11940	2 x 18650
$P_{I(cruise)}$ (kW)	-	2 x 4775	2 x 4775	2 x 5370	2 x 4775	2 x 11940	-
Configuration	X-connect	COGOG	COGAG	CODOG	COGAG	COGAG	X-connect
FC_{20} (t/hour)	2.47	2.57	2.63	2.07	2.69	3.00	2.57
$V_{MAX(5\,m)}$	22.8	23.5	23.6	24.0	23.5	21.6	23.5
$V_{MAX(5\,m)}$	30.1	30.1	30.0	30.0	31.5	30.0	30.2

increase with increasing displacement and length. The variation of cruise and main engines has a significant effect on platform acquisition cost. For example, consider ships A1 and C1; ship C1 is 170 tonnes heavier and 13.2 metres longer, but has lower platform acquisition cost due to its lower installed propulsion power.

By comparing the performance of the design candidates with the original requirements, it is apparent that the 2500 nautical mile range requirement at 30 knots is dominant. This became obvious early in the design process, as the displacement of ships otherwise acceptable had to be increased significantly to obtain sufficient fuel. Thus, the designer may feel that these design requirements are unbalanced, and it may be worth investigating the effects of reducing the required range at design speed. This option was investigated by reducing the design-speed range requirement to 2000 nautical miles, and the results are shown in Table 7. These ships are essentially scaled-down versions of those shown in Table 6, and are listed in the corresponding order.

In most cases, there is no significant reduction in platform acquisition cost between the two groups of design candidates, but the generally lower fuel consumption at cruise speed (20 knots) and reduced complement will provide significant reductions in future operational costs.

The last ship shown in Table 7, labelled A3, is a variant of ship A2 which is included to illustrate how decisions made by the designer in controlling the design process affect the

design solution. Ship A2 was derived from A1 by simply reducing displacement and length to match the reduced range at design speed. Since volume requirements remain constant (except for a small difference due to reducing complement), the superstructure volume of A2 is significantly larger than for A1 (4153 m^3 vs 2710 m^3). A different approach was used to generate ship A3, in which displacement was reduced but length was held approximately constant. In this case, ships A1 and A3 have approximately the same superstructure volume and the relatively low resistance of A3 with respect to the shorter A2 results in a lower displacement for A3.

The final comments on these design candidates concerns another aspect of the impact of designer's decisions on the design solution. Ships C1 and C2 were generated by increasing ship length until the powering requirements could be satisfied by relatively low installed power; however, it was not possible to generate these ships without changing the SHOP5 default calculations for the number of internal bulkheads, N_{bulk}, and waterplane coefficient, C_W. Originally, all likely candidates for this long hull form were rejected by SHOP5 for exceeding the maximum vertical centre of gravity for positive stability in the damaged condition, $\overline{KG}_{max}$ (described in Reference 1). This criterion was temporarily by-passed by defining a large user-supplied value for $\overline{KG}_{max}$ of 10.0 metres, and so ships generated from subsequent input files were effectively not limited by this criterion. With this constraint removed, a number of design candidates were generated and the FIVPOS graphics showed that many had adequate intact stability. Thus, if the damaged stability characteristics of these ships could be improved without degrading other performance parameters, it should be possible to generate acceptable design candidates. This was done by increasing N_{bulk} from the default value of 16 to 17, and by increasing C_W from the default of 0.728 to 0.768. Subsequent runs of SHOP5 with these modified values for N_{bulk} and C_W produced design candidate C1, which also satisfies the $\overline{KG}_{max}$ criterion. An additional change was necessary before ship C2 could be generated, as the mininum superstructure volume used in the procedure for sizing the superstructure produced over-large superstructures for these ships, causing inadequate intact stability due to relatively high vertical centres of gravity. The FIVPOS graphics for these ships showed that these ships had excess combat system volume, which indicated that it may be possible to increase $\overline{GM}/B$ by reducing superstructure volume, and still satisfy the combat system requirements. This was done by defining a reduced value for the minimum superstructure volume, and resulted in ship C2.

This entire design exercise, including investigating the reduced design-speed range requirement was performed by a single person in three days. Thus, the designer can rapidly initialize more detailed design by selecting one (or more) of the ships from Table 6, and can also indicate that significant savings in operational costs are possible if the design-speed range requirement is reduced.

8 Other uses for the SHOP5 System

Most of this documentation assumes that SHOP5 is being used to initialize the new-ship design process; however, it is a useful tool for other purposes, including:

- evaluating the effects of new or different technologies on ship size, performance and relative cost [3] ;
- evaluating the relative impact of design requirements and design practice (i.e. margins, methodology, etc.) on the ship platform;
- initial evaluation of design proposals or major refit/modernization programs;
- comparative naval architecture [9];
- initializing and/or performing specific parametric studies (e.g. [10]); and,
- in conjunction with other CEMs, evaluating the relative merits of the monohull frigate/destroyer for anticipated future requirements.

Of course, the level of detail used by SHOP5 means that it does not perform all calculations required for these purposes, but it is a useful tool in all cases. For example, the process of modeling a design proposal or foreign ship with SHOP5 rapidly highlights any anomalies (i.e. standard of accomodations, machinery space vs installed power, propulsive efficiency vs contemporary practice, etc.).

9 Concluding Remarks

The SHOP5 System provides a fast, flexible and user-friendly design tool for Concept Exploration design of monohull frigates and destroyers. The system has three major components; program FIVPRE for defining and modifying input, program SHOP5 for analysing the ships described by the input, and program FIVPOS for examining the characteristics of feasible design candidates using computer graphics.

The design logic used in SHOP5 is relatively simple; given ship size, hull form, major systems and design requirements, SHOP5 calculates performance and capability, including: deck wetness, vertical accelerations, and slam force in head seas; resistance, powering and range in calm water and waves; propulsion and electrical generation systems modeling and performance; distribution of weight and volume components; preliminary intact and damaged stability analysis; and a platform acquisition cost. This cost does not include any combat system or future operating costs, and is not sufficiently detailed for budgetary purposes; however, it is a valuable comparative parameter for performing design trade-offs.

The SHOP5 input consists of the ship description, design requirements and design criteria. Most of these parameters have pre-programmed default values representative of contemporary NATO practice, which can be redefined by user-supplied input for cases when the defaults are not appropriate. SHOP5 can be used in either a SEARCH or DESCRIBE mode. In the SEARCH mode, the designer specifies a range of ship sizes and underwater hull form coefficients, which defines a multi-dimensional search space. Each combination of ship size and hull form coefficients produces a possible design candidate, and up to 800

[3]SHOP5 does not explicitly consider operating costs, but it does provide key information, especially fuel consumption.

can be considered on a single execution of the program. When an individual ship does not satisfy all design criteria, then it is rejected and the next possible ship is considered. The characteristics of feasible ships are transferred to program FIVPOS, where the designer uses computer graphics to examine and select possible design candidates. The closed-loop structure of the SHOP5 System allows the user to transfer ship data from FIVPOS to FIVPRE, where they are arranged to form a new input file for SHOP5. This file can be used immediately to examine the selected ships in the DESCRIBE mode, or it can be modified to form a new SEARCH mode input file. In the DESCRIBE mode, more detailed calculations are performed for up to eleven individual ships and no ships are rejected. This mode is used to model existing ships for direct comparison with design candidates generated by SHOP5 and to examine ships rejected in the SEARCH mode.

The primary application for SHOP5 is to initialize the new-ship design process by determining the size, hull form and major systems of the ship or ships best suited for the design requirements. The iterative process used for design optimization was illustrated by generating a number of design candidates for a typical frigate mission. Also, this example emphasized the designer's responsibility for configuring suitable input and selecting appropriate design candidates. All SHOP5 input parameters and algorithms for design calculations were described in detail, with special attention to the options for replacing input parameter default values and internal calculations with user-supplied input.

Other uses for the SHOP5 System include assessing the effects of new or different technologies, design requirements and design practice on performance and capability, initial evaluation of design proposals and major refit or modernization programs, comparative naval architecutre, performing special parametric studies, and examining future requirements.

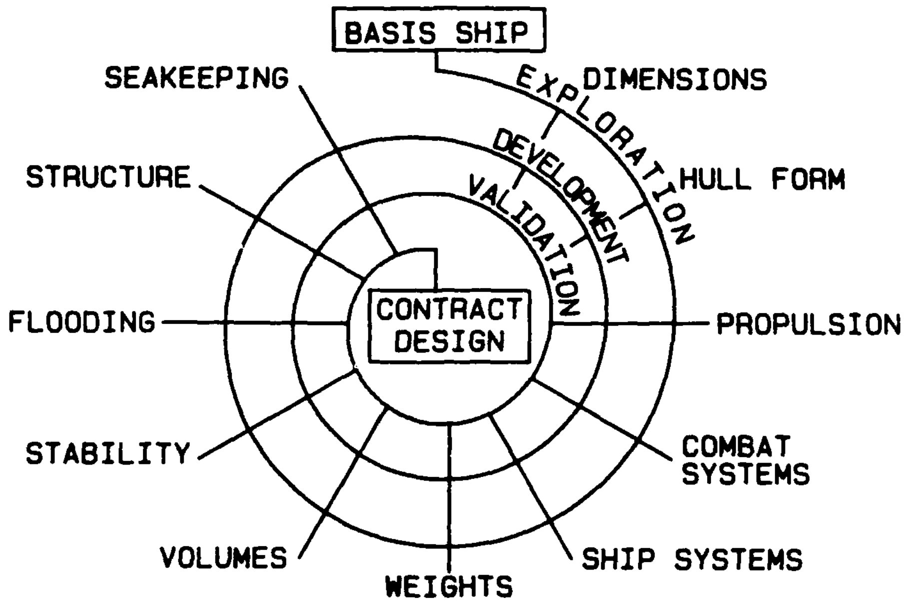

Figure 1: Traditional Design Spiral

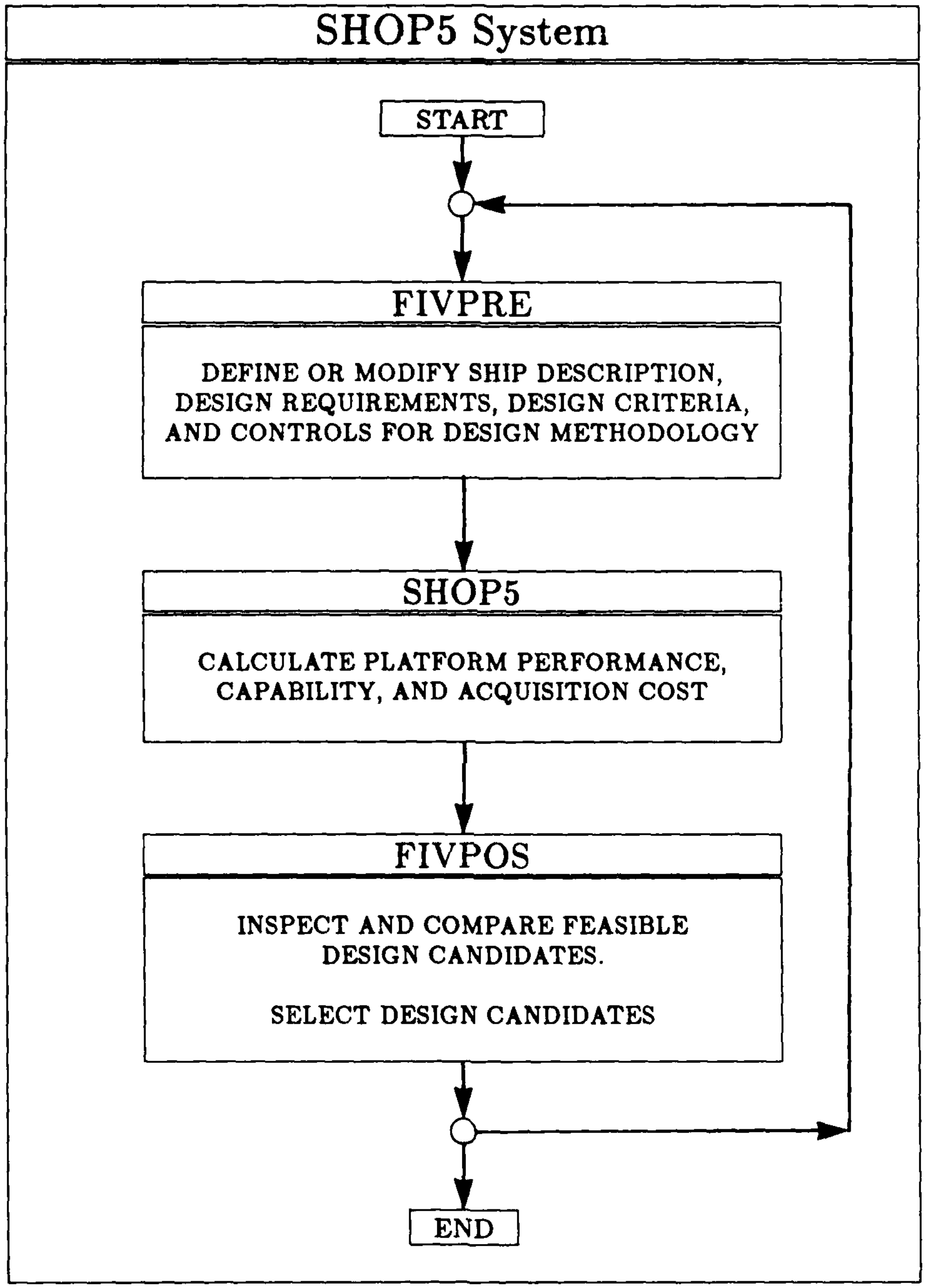

Figure 2: SHOP5 System Programs

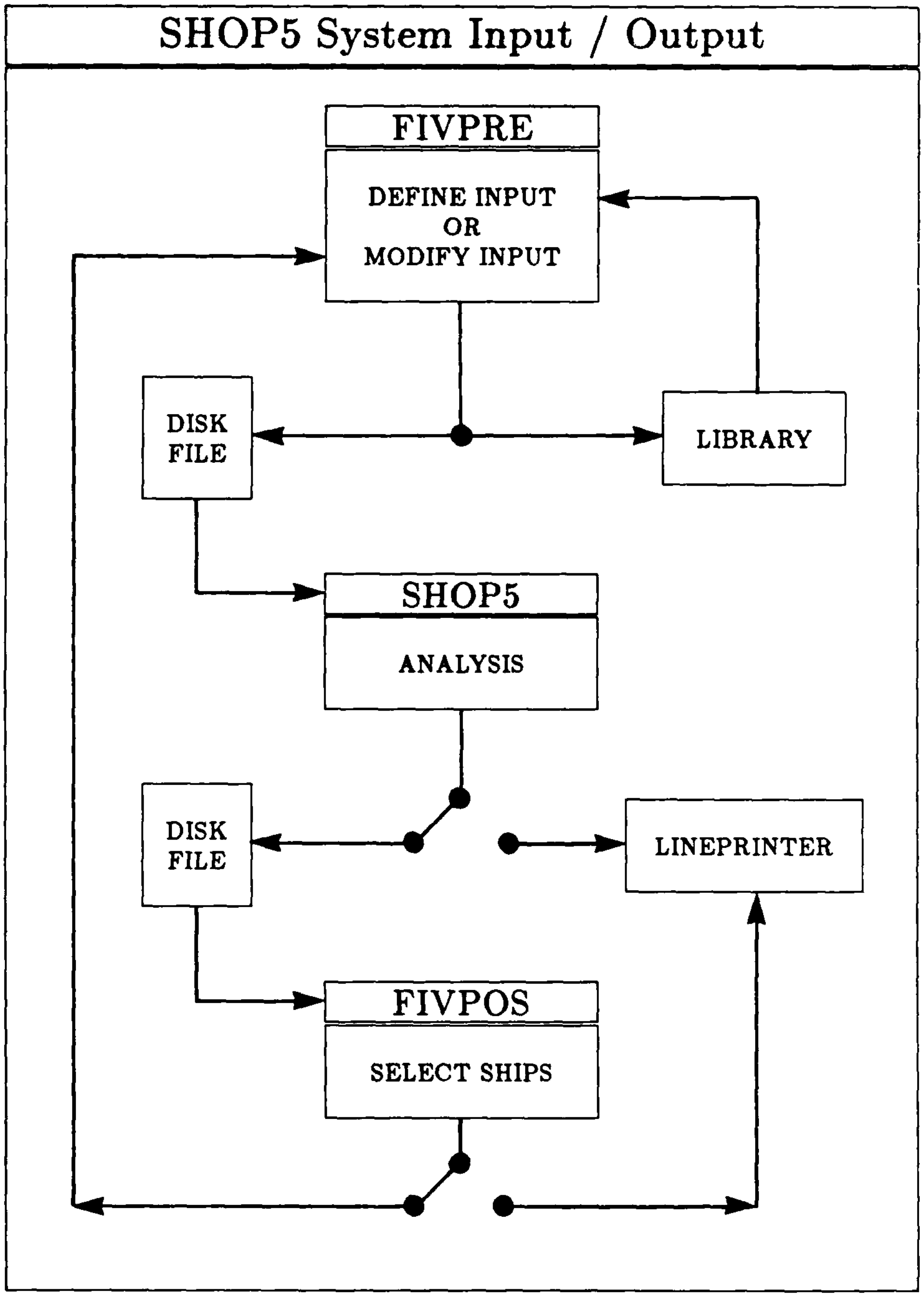

Figure 3: SHOP5 System Input and Output

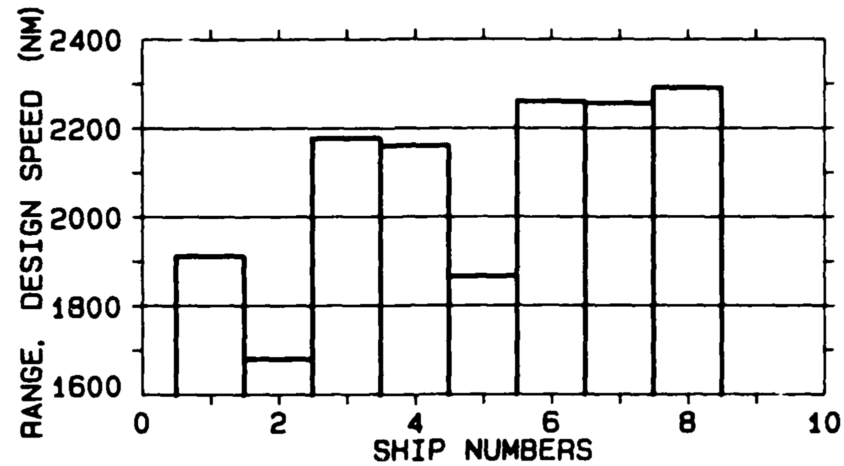

Figure 4: Range at Design Speed, 'First-Run' Ships

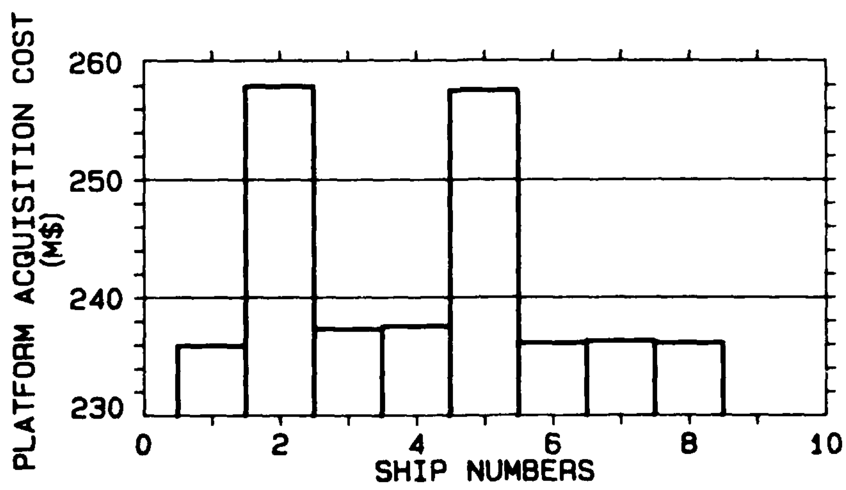

Figure 5: Platform Acquisition Cost, First-Run Ships

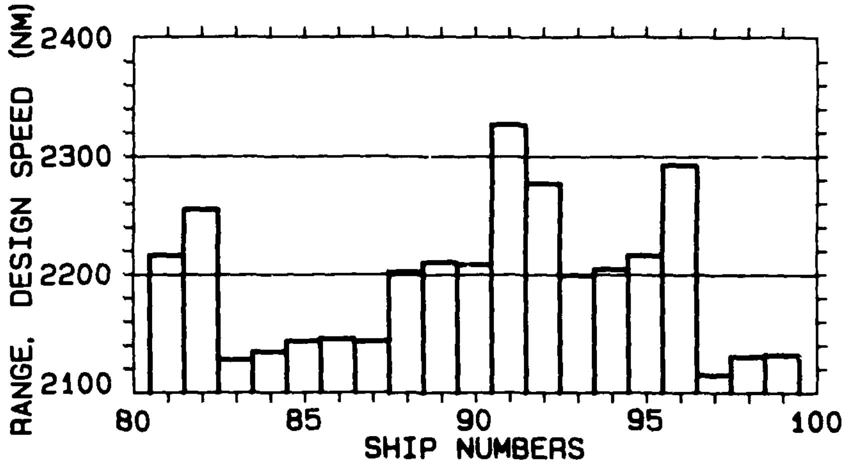

Figure 6: Range at Design Speed, 'Second-Run' Ships

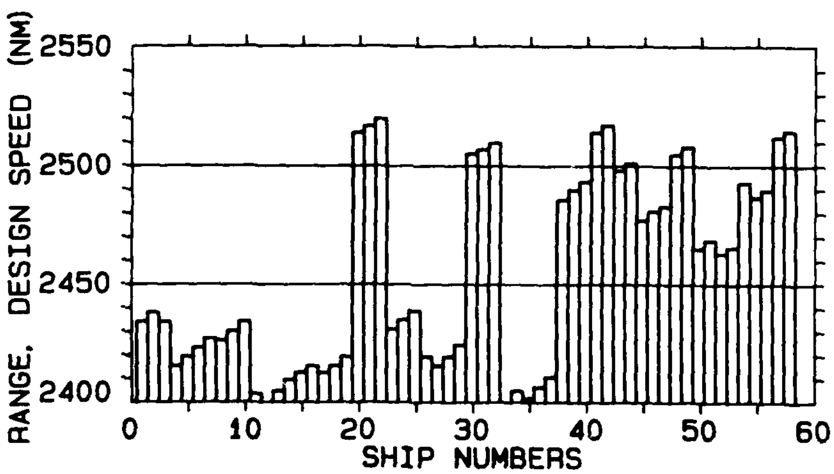

Figure 7: Range at Design Speed, 'Final-Run' Ships

Appendix A: SHOP5 Input Records

Overview of SHOP5 Input Records

The SHOP5 input parameters are arranged in the following records.

Record 1	Title
Record 2	Program Control Integers (PCI)
Record 3	Primary Input (PRIM)
Record 4	Method Control Integers (MCI)
Record 5	Optional Input Parameters (OPT)
Record 6	Design/Seakeeping Criteria (CRIT)
Record 7	Appendage Resistance Coefficient (IAPPND)
Record 8	Overall Propulsive Coefficients (IPROP)
Record 9	Superstructure Material (ISTRUC)
Record 10	Propulsion System (IENGIN)
Record 11	Electrical Generation System (IGEN)
Record 12	Superstructure Size Variations (IVOLUM)
Record 13	Cost Factors (ICOST)

Uppercase letters in (...) brackets define names recognized by FIVPRE for invoking parameter-access menus. For example, the FIVPRE command CHANGE MCI invokes the menu for changing method control integers. Records 1, 2 and 3 are required input. Records 4, 5 and 6 are optional and one or more of Records 7 through 13 may be required to define additional input for Record 4.

The following descriptions of the SHOP5 input records use the SHOP5 lineprinter notation for all parameter names, which is also used on-screen by FIVPRE and FIVPOS, and on all SHOP5 System lineprinter output. The Notation section at the front of this Technical Memorandum has separate entries for parameters whose lineprinter notation is significantly different from that used in the text.

When using program FIVPRE, some of the SHOP5 input parameters are defined automatically, and so the user does not have explicit knowledge of all required input. The differences between the on-screen input structure used by FIVPRE and the on-disk input structure required by SHOP5 are only important when the user is defining or modifying an input file without using FIVPRE. In this case, Appendices A and B provide complete documentation of the SHOP5 input record structure.

An example input file is presented in Table A.9 at the end of this appendix.

Record 1: Title

TITLE   Maximum of 80 characters, first line of file

Record 2: Program Control Integers

MODE   Defines type of mode: SEARCH or DESCRIBE
- 0 SEARCH mode
- n DESCRIBE mode, n = number of ships, $1 \leq n \leq 11$

UNITS   Defines type of units for input and output $0 \leq$ UNITS ≤ 3

0	Input FPS,	Output FPS
1	Input METRIC,	Output FPS
2	Input FPS,	Output METRIC
3	Input METRIC,	Output METRIC

IPOST   Will post-processor (FIVPOS) be used?
- 0 NO post-processor not used
- 1 YES post-processor will be used

Notes: (a) in SEARCH mode, if IPOST = 0, define ILPT = 1
if IPOST = 1, define ILPT = 0
(b) in DESCRIBE mode, define IPOST = 0

ILPT   Will SEARCH mode ship data be written to lineprinter ?
- 0 NO ship data not written to lineprinter
- 1 YES ship data written to lineprinter, one page per ship

Notes: (a) summary of input always written to lineprinter
(b) see Note (a) for IPOST, above.
(c) in DESCRIBE mode, define ILPT = 1

LEGEND   Will a legend of abbreviations accompany the lineprinter output ?
- 0 NO legend not written
- 1 YES legend written to lineprinter

NCON   number of method control integers redefined (see Record 4)

NOPT   number of optional input parameters redefined (see Record 5)

NLIM   number of design criteria redefined (see Record 6)

Order of input: eight integers on one line.

Record 3: Primary Input

The primary input define the characteristic dimension, underwater hull form and design requirements. These input are separated into two sub-records; Record 3A for the SEARCH mode and Record 3B for the DESCRIBE mode.

Record 3A: SEARCH Mode Primary Input

Only used when program control integer `MODE` = 0 (Record 2).

	Characteristic dimension: (see `IDIMEN`, Record 4)
`XXXlo`	low value
`XXXhi`	high value
`I1`	number of values, $1 \leq I1 \leq 11$
	Length/Displacement ratio, Ⓜ:
`CrMlo`	low value
`CrMhi`	high value
`I2`	number of values, $1 \leq I2 \leq 11$
	Prismatic coefficient:
`CPlo`	low value
`CPhi`	high value
`I3`	number of values, $1 \leq I3 \leq 11$
	Block Coefficient:
`CBlo`	low value
`CBhi`	high value
`I4`	number of values, $1 \leq I4 \leq 11$
	Beam/Draft ratio:
`B/Tlo`	low value
`B/Thi`	high value
`I5`	number of values, $1 \leq I5 \leq 11$

Note: maximum total number of ships is 800 (i.e. $\prod_{i=1}^{5} Ii \leq 800$)

`R(Ve)`	Minimum acceptable range (n. miles) at endurance speed, Ve
`Wc`	Combat systems weight (t:ton)
`Vd`	Design speed (knots)
`Vc`	Cruise speed (knots)
`Ve`	Endurance speed (knots)
`Vw`	Seakeeping speed (knots)
`Hw`	Seakeeping significant wave height (m:ft)

Order of input: XXXlo XXXhi I1
CrMlo CrMhi I2
Cplo Cphi I3
Cblo Cbhi I4
B/Tlo B/Thi I5
R(Ve) Wc Vd Vc Ve Vw Hw

Record 3B: DESCRIBE Mode Primary Input

Only used when program control integer MODE > 0 (Record 2).

XXX	Characteristic dimension (see IDIMEN, Record 4)
CrM	Length/Displacement ratio, M
Cp	Prismatic coefficient
Cb	Block coefficient
B/T	Beam/Draft ratio
Wc	Combat systems weight (t:ton)
Vd	Design speed (knots)
Vc	Cruise speed (knots)
Ve	Endurance speed (knots)
Vw	Seakeeping speed (knots)
Hw	Seakeeping significant wave height (m:ft)

Notes: (a) number of ships = MODE (Record 2)
(b) every ship requires explicit input for each parameter

Order of input:	XXX	CrM	Cp	Cb	B/T	Wc	Vd	Vc	Ve	Vw	Hw
for example:	4000	8.5	0.60	0.49	2.95	350	32	20	15	20	5
(MODE = 3)	4200	8.5	0.60	0.49	2.95	350	32	20	15	20	5
	4400	8.5	0.60	0.49	2.95	350	32	20	15	20	5

Record 4: Method Control Integers

Only used when program control integer NCON > 0 (Record 2).

I — Integer descriptor number of MCI being redefined

J(I) — Integer value of MCI(I)

Notes: (a) Acceptable I and J(I) values are shown in Table A.1, below.

Table A.1: Method Control Integers

I	Name	J(I)	Option	Additional Input
1	IDIMEN Characteristic Dimension	0	displacement (t:ton)	no
		1	length (m:ft)	no
		2	beam (m:ft)	no
		3	draft (m:ft)	no
2	IRESID Residuary Resistance	0	NRC FSS	no
		1	other SHOP5 database	no
3	IAPPND Appendage Resistance	0	SHOP5	no
		1	user-defined	Record 7
4	IPROP Propulsive Efficicency	0	SHOP5 CPP	no
		1	SHOP5 fixed pitch	no
		2	user-defined OPCs	Record 8
5	ISTRUC Structural Material	0	homogeneous	no
		1	hybrid	Record 9
6	IENGIN Propulsion System	0	SHOP5 rubber engines	no
		1	user-defined rubber engines	Record 10A
		2	SHOP5 real engines	Record 10B
		3	user-defined real engines	Record 10C
7	ICONFG Engine Configuration	0	fixed configuration	no
		1	variable configuration	Record 10D
8	IGEN Electrical Generation	0	SHOP5 diesel	no
		1	SHOP5 gas turbine	no
		2	user-defined	Record 11
		3	SHOP5 integrated	no
9	IVOLUM Superstructure Volume	0	Vsuper fixed	no
		1	Vsuper = f(Vcombat)	Record 12
		2	Vsuper = f(GM/B)	Record 12
10	ICOST Cost Factors	0	SHOP5	no
		1	user-defined	Record 13

(b) IDIMEN and ICONFG are not explicitly defined as method control integers in FIVPRE.

Order of input: I J

	I	J	
for example:	1	1	(i.e. characteristic dimension: length)
(NCON = 3)	6	2	(i.e. propulsion system: SHOP5 real engines)
	7	1	(i.e. electrical generators: SHOP5 gas turbines)

Record 5: Optional Input Parameters

Only used when program control integer NOPT > 0 (Record 2).

I	Integer descriptor number of parameter being redefined
X(I)	Real or integer value of parameter(I)

Note: see Appendix B (page 48) for values of I and X(I).

Order of input:	I	X(I)	
for example:	1	10	(i.e. D = 10 m)
(NOPT = 4)	5	220	(i.e. N = 220)
	8	-15	(i.e. Ldamage/L = 15)
	41	-16	(i.e. Vn/N = 16 m^3/person)

Record 6: Design Criteria

Only used when program control integer NLIM > 0 (Record 2).

I	Integer descriptor number of criterion being redefined
X(I)	Real or integer value of criterion(I)

Notes: (a) Acceptable input for I and X(I) are shown in the Table A.2, below.

Table A.2: Redefinable Design Criteria

I	Name	Default	User-Supplied Input, X(I)
1	WetMax	60 wetness/hour	WetMax = X(I)
2	AccMax	0.20 gravities	AccMax = X(I)
3	SlmMax	0.20	SlmMax = X(I)
4	EffMin	50.0 percent	EffMin = X(I)
7	OPCmin	0.60	OPCMin = X(I)
10	KGmax	calculated	X(I) > 0 ⇒ KGmax = X(I) X(I) < 0 ⇒ KGmax/D = |X(I)|
11	Vcombat	Vcombat/Vt = 0.125	X(I) > 0 ⇒ Vcombat = X(I) X(I) < 0 ⇒ Vcombat/Vt = |X(I)|

(b) The missing I values in Table A.2 are for design criteria that cannot be redefined by user-supplied input (e.g. minimum freeboard for reserve buoyancy).

Order of input:	I	X	
for example:	1	30	(i.e. WetMax = 30)
(NLIM = 2)	11	2900	(i.e. Vcombat = 2900 m^3)

Record 7: Appendage Resistance Coefficient

Only used when method control integer IAPPND = 1 (Record 4).

Capp	Appendage resistance coefficient, dimensionless

Note: input must be defined; input of zero gives Rapp = 0

Record 8: Overall Propulsive Coefficients

Only used when method control integer IPROP = 2 (Record 4).

OPC(Vd)	Overall propulsive coefficient at design speed
OPC(Vc)	Overall propulsive coefficient at cruise speed
OPC(Ve)	Overall propulsive coefficient at endurance speed

Note: input must be defined for all parameters; no defaults available.

Order of input:	OPC(Vd)	OPC(Vc)	OPC(Ve)
for example:	0.615	0.654	0.682

Record 9: Superstructure Material

Only used when method control integer ISTRUC = 1 (Record 4).

SSdens	Density of superstructure material (t/m^3:ton/ft^3) Default (SSdens = 0): aluminum, SSdens = 2.81 t/m^3 (0.075 ton/ft^3)
SSthck	Average thickness of superstructure material (m:ft) Default (SSthck = 0): aluminum, SSthck = 0.016 m (0.053 ft)

Note: input must be defined for both parameters; enter zero for default(s).

Order of input:	SSdens	SSthck	
for example:	0.0	0.020	(i.e. SSdens = 2.81 t/m^3, SSthck = 0.020 m)

Record 10: Propulsion System

Only used when method control integer IENGIN > 0 and/or ICHOOS = 1 (Record 4). The propulsion system sub-record structure is defined in Table A.3, below.

Table A.3: Propulsion System Sub-Records		
IENGIN = 1	Record 10A	user-defined rubber engines
IENGIN = 2	Record 10B	SHOP5 real engine database
IENGIN = 3	Record 10C	user-defined real engine database
ICONFG = 1	Record 10D	variable engine configuration

Record 10A: User-Defined Rubber Engines

Only used when method control integer IENGIN = 1 (Record 4).

SpW2 Propulsion system specific weight, W2/Pins (kg/kW:lb/HP)
Default (SpW2 = 0): SHOP5 rubber engines, approximates COGOG

KG2 Propulsion system vertical centre of gravity (m:ft) -[KG2/D]
Default (KG2 = 0): KG2/D = 0.4

Nsfc Number of (SFCr, P/Pins) data-pairs input below, $0 \leq$ Nsfc ≤ 11
Default (Nsfc = 0): SHOP5 rubber engines, approximates COGOG and SFCr(I) and P/Pins(I) not input.

SFCr(I) Specific fuel consumption (kg/kW-hr:lb/HP-hr) at power ratio P/Pins(I)
Note: SFCr(1) must be full power SFC, SFCo

P/Pins(I) Power ratio (operating power/installed power) for SFCr(I)
Notes: (a) P/Pins(1) must = 1.00 (i.e. full power)
(b) P/Pins values must be in descending order (i.e. P/Pins(I+1) < P/Pins(I))

Order of input:	SpW2	KG2	Nsfc
	SFCr(1)	P/Pins(1)	
	SFCr(2)	P/Pins(2)	
	...	...	
	SFCr(Nsfc)	P/Pins(Nsfc)	
for example:	5.36	-0.3	4
	0.20	1.00	
	0.23	0.80	
	0.28	0.60	
	0.38	0.40	

Record 10B: SHOP5 Real Engines

Only used when method control integer IENGIN = 2 (Record 4).

ITYPE Type of engine configuration per shaft, $1 \leq$ ITYPE ≤ 6

1 Single gas turbine
2 COGAG
3 COGOG
4 CODAG
5 CODOG
6 CODAD

IDBASE Engine data base selection, $0 \leq$ IDBASE ≤ 1

0 1980 engine data base, see Table A.4
1 1995 engine data base, see Table A.5

Table A.4: 1980 Engine Data Base

Name	Type	P_i		SFC_o		W_{2a}	
		(kW)	(HP)	$\left(\frac{kg}{kW\ hr}\right)$	$\left(\frac{lb}{HP\ hr}\right)$	(tonne)	(ton)
LM 2500	g.t.	18,650	25,000	0.23	0.38	15.65	15.40
Spey	g.t.	11,936	16,000	0.24	0.39	9.30	9.15
DDA 570	g.t.	4,774	6,400	0.28	0.46	2.27	2.23
Pielstick	diesel	5,371	7,200	0.23	0.38	42.98	42.30
MTU	diesel	3,730	5,000	0.23	0.38	33.83	33.30

Table A.5: 1995 Engine Data Base

Name	Type	P_i		SFC_o		W_{2a}	
		(kW)	(HP)	$\left(\frac{kg}{kW\ hr}\right)$	$\left(\frac{lb}{HP\ hr}\right)$	(tonne)	(ton)
LM 5000	g.t.	44,760	60,000	0.21	0.34	35.15	34.60
FT 9	g.t.	33,570	45,000	0.21	0.35	21.09	20.76
LM 2500	g.t.	22,380	30,000	0.22	0.37	15.65	15.40
Spey	g.t.	17,904	24,000	0.23	0.38	9.30	9.15
DDA 570	g.t.	5,968	8,000	0.28	0.46	2.27	2.23
Pielstick	diesel	7,460	10,000	0.23	0.38	42.98	42.30
MTU	diesel	4,476	6,000	0.23	0.38	33.83	33.30

Order of input: ITYPE IDBASE

for example: 2 0 (i.e. COGAG configuration, 1980 data base)

Record 10C: User-defined Real Engines

Only used when method control integer IENGIN = 3 (Record 4).

ITYPE	Type of engine configuration per shaft, $1 \leq$ ITYPE ≤ 6 1 Single gas turbine 2 COGAG 3 COGOG 4 CODAG 5 CODOG 6 CODAD
SpW2b	Specific weight of propulsion system not including engines SpW2b = (W2 - (W2a)Nshaft)/Pins (kg/kW:lb/HP) Default (SpW2b = 0): Nshaft = 2, SpW2 = 7.72 kg/kW (12.7 lb/HP) Nshaft = 1, SpW2 = 7.30 kg/kW (12.0 lb/HP)
KG2	Propulsion system vertical centre of gravity (m:ft) -[KG2/D] Default (KG2 = 0): KG2/D = 0.4
Nturb	Number of gas turbine engines, $0 \leq$ Nturb ≤ 8
NAME(I)	Name of engine(I), maximum 16 characters
Pi(I)	Full power of engine(I) (kW:HP)
SFCo(I)	Full power specific fuel consumption of engine(I) (kg/kW-hr:lb/HP-hr)
W2a(I)	Weight of engine(I) (t:ton), includes acoustic isolation module
Ndies	Number of diesel engines, $0 \leq$ Ndies ≤ 4
NAME(I)	Name of engine(I), maximum 16 characters
Pi(I)	Full power of engine(I) (kW:HP)
SFCo(I)	Full power specific fuel consumption of engine(I) (kg/kW-hr:lb/HP-hr)
W2a(I)	Weight of engine(I) (t:ton), includes acoustic isolation module

Notes:
(a) ITYPE, SpW2b, KG2, Nturb and Ndies must be input. If Nturb and/or Ndies is zero, corresponding NAME, Pi, SFCo and W2a are not input.
(b) Order of input and example input are on next page.

Order of input:	ITYPE	SpW2b	KG2
	Nturb		
	NAME(1)		
	Pi(1)	SFCo(1)	W2a(1)
	NAME(2)		
	Pi(2)	SFCo(2)	W2a(2)
	...		
	...	...	...
	NAME(Nturb)		
	Pi(Nturb)	SFCo(Nturb)	W2a(Nturb)
	Ndies		
	NAME(1)		
	Pi(1)	SFCo(1)	W2a(1)
	NAME(2)		
	Pi(2)	SFCo(2)	W2a(2)
	...		
	...	...	...
	NAME(Nturb)		
	Pi(Ndies)	SFCo(Ndies)	W2a(Ndies)
for example:	5	7.2	-0.35
	3		
	BIG TURBINE		
	20000.	0.20	25.0
	MEDIUM TURBINE		
	15000.	0.22	12.0
	SMALL TURBINE		
	7500.	0.24	3.0
	2		
	BIG DIESEL		
	10000.	0.21	45.5
	SMALL DIESEL		
	4000.	0.21	30.0

Record 10D: Variable Engine Configuration

Only used when method control integer ICHOOS = 1 (Record 4).
This option should be used with caution, see Reference 1 for further comments.

IHIAR — Integer descriptor of engine configuration hierarchy, $0 \leq$ IHIAR ≤ 3

- 0 SHOP5 noise hierarchy, see Table A.6
- 1 SHOP5 gearing hierarchy, see Table A.6
- 2 SHOP5 powering hierarchy, see Table A.6
- 3 User-defined hierarchy, see NHIAR(I), below.

Table A.6: SHOP5 Hierarchies

Noise	Gearing	Power
CODAD	CODAG	COGAG
CODAG	COGAG	CODAG
COGAG	COGOG	COGOG
CODOG	CODOG	CODOG
COGOG	CODAD	CODAD
Single	Single	Single

NHIAR(I) — Integer descriptors of user-defined engine configuration hierarchy,

Notes:
- (a) NHIAR values only input when IHIAR = 3
- (b) When used, six values for NHIAR must be input
- (c) NHIAR integer descriptors shown in Table A.7

Table A.7: Hierarchy Descriptors

NHIAR	Configuration per shaft
1	Single gas turbine
2	COGAG
3	COGOG
4	CODAG
5	CODOG
6	CODAD

Order of input: IHIAR
NHIAR(1) NHIAR(2) NHIAR(3) NHIAR(4) NHIAR(5) NHIAR(6)

for example: 3
6 5 4 3 2 1

Record 11: Electrical Generation System

Only used when method control integer IGEN = 2 (Record 4).

SpW3	Specific weight of electrical systems (kg/kW:lb/kW) SpW3 = W3/Pgen Default (SpW3 = 0): SHOP5 diesel generators
KG3	Electrical systems vertical centre of gravity (m:ft) -[KG3/D] Default (KG3 = 0): SHOP5 calculation
SFCg	Specific fuel consumption of generators (kg/kW-hr:lb/kW-hr) Default (SFCg = 0): SHOP5 diesel generators

Order of input: SpW3 KG3 SFCg

for example: 50.0 -0.75 0.0

Record 12: Superstructure Size Variations

Only used when method control integer IVOLUM > 0 (Record 4).

VsMin	Minimum superstructure volume (m^3:ft^3) -[VsMin/Vt] Default (VsMin = 0): SHOP5 calculation, assumes hangar
VsMax	Maximum superstructure volume (m^3:ft^3) -[VsMax/Vt] Default (VsMax = 0): SHOP5 calculation
GM/B	Target value for metacentric height/beam ratio, see note (a). Default (GM/B = 0): GM/B = 0.10

Notes:
(a) GM/B only input when IVOLUM = 2.
(b) When IVOLUM = 1, target value for combat systems volume is defined by Vcombat, design criterion (Record 6).

Order of input: VsMin VsMax GM/B (assume IVOLUM = 2)

for example: 1750. -0.32 0.08

Record 13: Cost Factors

Only used when method control integer ICOST = 1 (Record 4).

NCOST	Number of cost factors being redefined
I	Integer descriptor of cost factor being defined, $1 \leq I \leq 16$
AK(I)	New value of cost factor(I)

Note: Table A.8 shows the cost categories for each value of I and also shows the SHOP5 default AK(I) values. See Reference 1 for information on the cost estimating equations and units of cost factors.

Table A.8: Cost Factors

I	Cost Category		Default AK(I)
1	Hull structure		18.00
2	Superstructure,	MCI ISTRUC = 0	18.00
		ISTRUC = 1	40.00
3	Not used by SHOP5		-
4	Diesel engines		1.25
5	Gas turbine engines		3.25
6	Electrical systems		150.00
7	Auxiliary systems		90.00
8	Outfit and furnishings		65.00
9	Shipyard construction		1.00
10	Design and engineering, lead ship		0.50
11	Design and engineering, follow-on ship		0.05
12	Construction services		0.40
13	Shipyard profit, lead ship		1.15
14	Shipyard profit, follow-on ship		1.15
15	Miscellaneous surcharges, lead ship		1.33
16	Miscellaneous surcharges, follow-on ship		1.28

Order of input:

```
NCOST
I(1)       AK(1)
I(2)       AK(2)
...        ...
I(NCOST)   AK(NCOST)
```

for example:

```
3
1          15.5
7          75.0
13         1.01
```

Example Input File

Table A.9 contains an example input file which defines input for most of the SHOP5 input records. This example input file is the same as the first file produced in the design optimization example in Appendix C. The "......Record (i)" notation in Table A.9 is only included for identifying individual input records; it is not normally present.

Table A.9: Example Input File

```
 DESIGN OPTIMIZATION, COGAG CONFIG. ....................Record (1)
 0    3    1    0    0    2    6    2 .................Record (2)
3500.000  4500.000    6 ..............................Record (3A)
   7.000     9.000    5                                  "    "
   0.590     0.590    1                                  "    "
   0.490     0.490    1                                  "    "
   2.800     3.200    5                                  "    "
 4500.00  375.00 30.00 20.00 20.00 20.00  5.00           "    "
  6  2 .................................................Record (4)
  9 11                                                   "    "
   1      10.0000 ......................................Record (5)
   5      -0.8800                                        "    "
   8      -0.1500                                        "    "
  19    4000.0000                                        "    "
  33      50.0000                                        "    "
  41     -16.0000                                        "    "
   1      30.0000 ......................................Record (6)
  11    2900.0000                                        "    "
 2  0 ..................................................Record (10)
 2 -0.3000 .............................................Record (12)
```

Appendix B: Optional Input Parameters

SHOP5 uses a total of 44 optional input parameters to define details of geometry, systems, environment and design margins. Each optional input parameter has a default value or method which is used when the parameter is not explicitly re-defined by the user. The algorithms used to calculate the defaults are described in Reference 1.

This appendix describes the optional input parameters, including; names, descriptions, units and defaults. Most names are a either a standard symbol (e.g. `Cw` for waterplane coefficient) or descriptive abbreviation (e.g. `Nshaft` for number of propeller shafts). The names are shown in the lineprinter format, which is also used on-screen by FIVPRE and FIVPOS, and on the SHOP5 and FIVPOS lineprinter output. When using program FIVPRE to prepare the SHOP5 input file, individual optional input parameters can be accessed using the CHANGE command (abbreviation C). The parameter is identified by entering either its name or part of its description (e.g. C CW or C WAT COEF).

This appendix uses the following format to describe each parameter.

I	`name`	description (units) -[negative definition]
		default value or method, and special notes

where I is the integer descriptor number defined in Record 5, Appendix A.

As indicated above, many of the optional input parameters accept either positive or negative input. In most cases, negative input defines a non-dimensional form of the parameter. For example (in metric units), input of 10 for midship hull depth, `D`, defines `D` = 10 metres; whereas, input of -12 defines the ratio `L/D` = 12. When negative input changes the definition of a parameter, then two names are shown. For example, consider the margin on personnel volume, dVn, which has the following description.

41	`dVn`	Margin on personnel volume, `Vn` (m^3:ft^3) -[`Vn/N`]
	`Vn/N`	Standard of Accomodation (m^3/person:ft^3/person)
		`Vn/N` is not a margin

This parameter has two definitions: for positive input, it is a margin, dVn (m^3:ft^3), which is added to the SHOP5 estimate for personnel volume, Vn; for negative input, it is the standard of accomodation (personnel volume/person ratio), `Vn/N` (m^3/person:ft^3/person). For example (in metric units), input of 200 for dVn defines dVn = 200 m^3, and the SHOP5 estimate for Vn is increased by 200 m^3. Conversely, input of -16 for dVn defines `Vn` = 16 `N` (m^3/person), and the SHOP5 algorithm for estimating Vn is not used.

The optional input parameters are grouped in categories defined by the FIVPRE menu shown below. This menu provides indirect access to all of the optional input parameters, and is used by the commands NEW and CHANGE OPTIONAL INPUT (i.e. C OPT).

```
   OPTIONAL INPUT
   --------------
1  GEOMETRY AND COMPLEMENT
2  SEAKEEPING
3  POWERING AND MACHINERY
4  STRUCTURE
5  WEIGHT AND STABILITY
6  VOLUME
7  MISSION
```

```
GEOMETRY AND COMPLEMENT
-----------------------
```

1	D	Midship hull depth (m:ft) -[L/D] Default: D = T + 0.04 L
2	Cw	Waterplane coefficient Default: Cw = 0.78 Cp + 0.33
3	LCB	Longitudinal centre of buoyancy (m:ft) -[LCB/L] Default: LCB/L = 0.515
4	LCF	Longitudinal centre of flotation (m:ft) -[LCF/L] Default: LCF/L = 0.557
5	N	Complement (accomodations) -[N/DISP$^{2/3}$] Default: N/DISP$^{2/3}$ = 1.0 (person/t)
6	Ndeck Dstruc	Number of internal decks (m:ft) -[Dstruc] Hull depth to strength deck (m:ft) Default: Ndeck = D/2.59 - 1 (m)
7	Nbulk Lbulk	Number of watertight compartments -[Lbulk] Average bulkhead spacing (m:ft) Default: Nbulk = SHOP5 calculation
8	C Ldamage	Standard of compartmentation -[Ldamage/L] Flooded length (note, defined as Ldamage/L) Default: C = 3
9	Lsuper	Superstructure length (m:ft) -[Lsuper/L] Default: Lsuper/L = 0.55

SEAKEEPING

10	Ffp	Freeboard at FP (m:ft) -[Ffp/L] Default: Ffp/L = 0.093 - 0.00021 L
11	To	Wave modal period, seakeeping (sec) Default: To = f(Hw), winter North Atlantic
12	AccHi	RMS vertical acceleration for zero percent crew effectiveness Default: AccHi = 0.25 (gravities)
13	AccLo	RMS vertical acceleration for 100 percent crew effectiveness Default: AccLo = 0.05 (gravities)

POWERING AND MACHINERY

14	Ca	Model-ship correlation allowance Default: Ca = 0.0005
15	dPe	Design margin on effective power, Pe Pe = $(1 + dPe)$ Rt V Default: dPe = 0.10 (i.e. 10 percent)
16	DIAM	Propeller diameter (m:ft) -[DIAM/T] Default: DIAM/T = 1.0 for Nshaft = 2 DIAM/T = 1.1 for Nshaft = 1
17	Nshaft	Number of propeller shafts Default: Nshaft = 2
18	Ngen	Number of ship service electrical generators Default: Ngen = 4
19	Pgen	Electrical power installed (kW) -[Pgen/DISP] Default: Pgen/DISP = 1.0 (kW/t)
20	avPgen	Average cruising electrical power (kW) -[avPgen/Pgen] Default: avPgen/Pgen = 0.25
21	Hw(r)	Significant wave height for powering and range (m:ft) -[Hw(r)/L] Default: Hw(r) = 3.0 (m)
22	To(r)	Wave modal period for powering and range (sec) Default: To(r) = f(Hw(r)), winter North Atlantic

STRUCTURE

23	YIELD	Yield strength of hull material (ton/in^2:t/cm^2) Default: steel, YIELD = 2.835 t/cm^2 (18.0 ton/in^2)
24	DENS	Density of hull material (ton/ft^3:t/m^3) Default: steel, DENS = 7.858 t/m^3 (0.219 ton/ft^3)
25	Fmod	Factor on structural modulus Fmod multiplies midship sectional modulus Default: Fmod = 1.0

WEIGHT AND STABILITY All default values for weight margins are zero.

26	dW1	Margin on structural weight, W1 (ton:t) -[dW1/W1]
27	dW2	Margin on machinery weight, W2 (ton:t) -[dW2/W2]
28	RAFT	Margin on engine rafting (ton:t) -[RAFT/W2]
29	GEAR	Margin on gear box weight (ton:t) -[GEAR/Pins]
30	dW3	Margin on electrical systems weight, W3 (ton:t) -[dW3/W3]
31	dW5	Margin on auxiliary systems weight, W5 (ton:t) -[dW5/W5]
32	dW6	Margin on outfit and furnishings weight, W6 (ton:t) -[dW6/W6]
33	dWb	Margin on Wbasic, (ton:t) -[dWb/Wb] Wbasic = W1 + W2 + W3 + W5 + W6 Use dWb for future growth margin
34	dWd	Margin on disposable loads weight, Wd (ton:t) -[dWd/Wd]
35	KGb	Vertical centre of gravity of dWb (m:ft) -[KGb/D] Default: KGb/D = 0.65
36	KGc	Vertical centre of gravity of Wcombat (m:ft) -[KGc/D] Default: KGc/D = 1.00

VOLUME — All default values for volume margins are zero.

------

37 Vsuper — Superstructure volume (m^3:ft^3) -[Vsuper/Vt]
Vsuper only used when method control integer IVOLUM = 0
Default: Vsuper/Vt = 0.30

38 dVm — Margin on machinery volume, Vm (m^3:ft^3) -[Vm/Pins]
Vm/Pins — Propulsion system volume/installed power ratio (m^3/kW:ft^3/HP)
Vm/Pins is not a margin

39 dVo — Margin on outfit and systems volume, Vo (m^3:ft^3) -[Vo/Vt]
Vo/Vt — Outfit and systems volume/Total enclosed volume ratio (dimensionless)
Vo/Vt is not a margin

40 dVb — Margin on Vbasic (m^3:ft^3), Vbasic = Vm + Vo -[dVb/Vt or dVhull]
dVhull — Reduction in calculated hull volume (m^3:ft^3),

$0 <$ input $\Rightarrow$ dVb, Vbasic = Vm + Vo + dVb
$-1 \leq$ input $\leq 0 \Rightarrow$ dVb/Vt, Vbasic = Vm + Vo + Vt|dVb/Vt|
input $< -1 \Rightarrow$ dVhull, Vhull = Vhull - |dVhull|

dVhull is not a margin

41 dVn — Margin on personnel volume, Vn (m^3:ft^3) -[Vn/N]
Vn/N — Standard of Accomodation (m^3/person:ft^3/person)
Vn/N is not a margin

MISSION

----

42 Td/T — Normalized time at design speed, Vd
Default: Td/T = 0.05

43 Tc/T — lizedtime at cruise speed, Vc
Default: Td/T = 0.30

44 Te/T — Normalized time at endurance speed, Ve
Default: Td/T = 0.65

Appendix C: Design Optimization Example, Session 1

This example terminal session demonstrates using FIVPRE to define a new SHOP5 input file and illustrates the iterative process of running SHOP5, examining ships with FIVPOS and re-defining the initial input to home-in on a desireable design candidate. None of the ships generated on the initial run have sufficient range at 30 knots, but some interesting trends regarding platform acquisition cost, range and superstructure volume are evident.

Most program menus for controlling input are shown only once; however, editorial comments indicate where text has been omitted. Editorial comments are delimited as follows,

```
---<editorial comments>---
```

All user-supplied input follows a "=>" prompt. When no input is shown after this prompt, then the user has simply pushed the Return key (i.e. "null" input), and a default response is used. The default response (or action) is defined within <...> brackets in the prompt-line. When no default response is defined, then null input means "preserve the current value".

```
SHOP5 System: Program Control
-----------------------------
 1  Run FIVPRE
 2  Run SHOP5
 3  Run FIVPOS
 4  Lineprinter Control
 5  Edit
 6  Help
99  EXIT

Enter NUMBER => 1

-----------------------------------------------------------

FIVPRE, Pre-processor for SHOP5
------------------------------

reading library file.....

FIVPRE: enter command => NEW

Enter TITLE => design optimization, COGAG config.

Program Control Integers (PCI)
-----------------------------

   MODE
   ----
0  SEARCH
1  DESCRIBE

MODE ?  <SEARCH> =>
```

```
   UNITS
   -----
0  Input: FPS      Output: FPS
1  Input: metric   Output: FPS
2  Input: FPS      Output: metric
3  Input: metric   Output: metric

UNITS ?  <metric-metric>  =>

   POST-PROCESSOR
   --------------
0  NO,  Post-processor (FIVPOS) will NOT be used
1  YES, Post-processor will be used

POST-PROCESSOR ?  <Yes> =>

   LEGEND
   ------
0  NO Legend
1  Legend of SHOP5 abbreviations written on lineprinter

LEGEND ?  <No> =>

   Characteristic Dimension (XXX)
   ------------------------------
0  Displacement (full load)
1  Length
2  Beam
3  Draft

Enter selection  <Displacement> =>

Primary Input (PRIM)
--------------------
DISP; Displacement (t:ton)              Minimum =>  3500
                                        Maximum =>  4500
                               Number of values =>  6

CrM;  Length/Displacement Ratio         Minimum =>  7
                                        Maximum =>  9
                               Number of values =>  5

Cp;   Prismatic Coefficient             Minimum =>  .59
                                        Maximum =>  .59

Cb;   Block Coefficient                 Minimum =>  .49
                                        Maximum =>  .49

B/T;  Beam/Draft Ratio                  Minimum =>  2.8
                                        Maximum =>  3.2
                               Number of values =>  5

Design Requirements
-------------------
R(Ve);   Range at Endurance Speed => 4500
Wcombat; Combat System Weight (t:ton) => 375
Vd;      Design Speed (kt) => 30
Vc;      Cruise Speed (kt) => 20
Ve;      Endurance Speed (kt) => 20
Vw;      Seakeeping Speed (kt) => 20
Hw;      Seakeeping Wave Height (m:ft) => 5
```

```
    Method Control Integers (MCI)
    -----------------------------
 1  IRESID; Residuary Resistance
 2  IAPPND; Appendage Resistance
 3  IPROP;  Propeller Type or OPC Values
 4  ISTRUC; Hull/Superstructure Material
 5  IENGIN; Propulsion System
 6  IGEN;   Ship Service Electrical Generators
 7  IVOLUM; Superstructure Sizing Method
 8  ICOST;  Cost Factors

Enter selection  <exit> => 5

   Propulsion System (IENGIN)
   --------------------------
0  SHOP5 Rubber Engines
1  User-Supplied Rubber Engines
2  SHOP5 Real Engines
3  User-Supplied Real Engines

Enter selection => 2

   Engine Data Base
   ----------------
0  1980 Engine Data Base
1  1995 Engine Data Base

Enter selection  <1980> =>

   Engine Configuration (ITYPE)
   ----------------------------
1  Single gas turbine
2  COGAG (COmbined Gas And Gas)
3  COGOG (COmbined Gas Or Gas)
4  CODAG (COmbined Diesel And Gas)
5  CODOG (COmbined Diesel Or Gas)
6  CODAD (COmbined Diesel And Diesel)

Enter selection => 2

   Engine Configuration Selection
   ------------------------------
0  SHOP5 must use this Configuration
1  SHOP5 may change Configuration (not recommended)

Enter selection  <must use> =>

---<omit MCI menu, select IVOLUM>---

   Volume Components (IVOLUM)
   --------------------------
0  Vcombat = f(Vsuper)
1  Vsuper = f(Vcombat)
2  Vsuper = f(GM/B)

Enter selection => 1

** WARNING **
You have changed the method for calculating superstructure
volume, Vsuper.  Vsuper is now determined by the target
value for combat system volume, Vcombat (design criterion).
```

```
** INFORMATION **

The following constraints on Vsuper are now active.

VsMin; minimum Superstructure Volume = f(L,B,D,Ndeck,Pins)
VsMax; maximum Superstructure Volume = f(Lsuper,B,D,Ndeck)

Note: the current default value for VsMax permits fairly
wide variation of Vsuper.  You can reduce the number of
design candidates by defining a more rigorous constraint.

CHANGE VsMin or VsMax ?  <Yes> =>

   Superstructure Volume Constraints
   ---------------------------------

1  VsMin; minimum Superstructure Volume.
2  VsMax; maximum Superstructure Volume.

Enter selection  <exit> => 2

VsMax; maximum Superstructure Volume = f(Lsuper,B,D,Ndeck)

VsMax; maximum Vsuper (m3:ft3) -[VsMax/Vt] => -0.30

---<omit VsMin/VsMax menu, select Exit>---
---<omit MCI menu, select Exit>---

   Optional Input (OPT)
   --------------------
1  Geometry and Complement
2  Seakeeping
3  Powering and Machinery
4  Structure
5  Weight and Stability
6  Volume
7  Mission

Enter selection  <exit> => 1

   Geometry and Complement
   -----------------------
1  D;      Midships Hull Depth
2  Cw;     Waterplane Coefficient
3  LCB;    Longitudinal Centre of Buoyancy
4  LCF;    Longitudinal Centre of Flotation
5  N;      Complement
6  Ndeck;  Number of Internal Decks [.OR. Dstruc]
7  Nbulk;  Number of Watertight Compartments
8  C;      Standard of Compartmentation [.OR. Ldamage]
9  Lsuper; Superstructure Length

Enter selection  <exit> => 1

Current Value (Default) =  D = T + 0.04 L

D;      Midship Hull Depth (m:ft) -[L/D] => 10

---<omit Geometry and Complement menu, select N (complement)>---
```

```
Current Value (Default) =  N/(DISP^(2/3)) = 1.0

N;      Complement -[N/DISP^(2/3)] => -0.88

---<omit Geometry and Complement menu, select C>---

Current Value (Default) =  3 Compartments

C;      Standard of Compartmentation -[Ldamage/L] => -0.15

---<omit Geometry and Complement menu, select Exit>---
---<omit OPT menu, select Powering and Machinery>---

   Powering and Machinery
   ----------------------
1  Ca;     Model-Ship Correlation Allowance
2  dPe;    Design Margin on Effective Power
3  DIAM;   Propeller Diameter
4  Nshaft; Number of Propeller Shafts
5  Ngen;   Number of Electrical Generators
6  Pgen;   Electrical Power Installed
7  avPgen; Average Cruise Electrical Power
8  Hw(r);  Significant Wave Height (range)
9  To(r);  Wave Modal Period (range)

Enter selection  <exit> => 6

Current Value (Default) =  Pgen/DISP = [-]1.0

Pgen;  Installed Generator Power (kW) -[Pgen/DISP] => 4000

---<omit Powering and Machinery menu, select Exit>---
---<omit OPT menu, select Weightand Stability>---

   Weight and Stability
   --------------------
 1  dW1;   Margin on Hull Structure Weight
 2  dW2;   Margin on Propulsion Machinery Weight
 3  RAFT;  Margin on Engine Rafting
 4  GEAR;  Margin on Gear Box
 5  dW3;   Margin on Electrical Weight
 6  dW5;   Margin on Auxiliaries Weight
 7  dW6;   Margin on Outfit & Furnishing Weight
 8  dWb;   Margin on Basic Weight (future growth)
 9  dWd;   Margin on Disposable Weight
10  KGb;   VCG of Margin on Basic Weight
11  KGc;   VCG of Combat System Weight

Enter selection  <exit> => 8

Current Value (Default) =  0.0

dWb;    MARGIN Wb, Basic Weight (t:ton) -[dWb/Wb] => 50

---<omit Weight and Stability menu, select Exit>---
---<omit OPT menu, select Volume>---
```

```
    Volume
    ------
 1  Vsuper; Superstructure Volume
 2  dVm;    Margin on Machinery Volume [.OR. Vm/Pins]
 3  dVo;    Margin on Outfit Volume    [.OR. Vo/Vt]
 4  dVb;    Margin on Basic Volume     [.OR. dVhull]
 5  dVn;    Margin on Personnel Volume [.OR. Vn/N]

 Enter selection  <exit> => 5

 Current Value (Default) =  0.0

 dVn;    MARGIN Personnel Volume (m3:ft3) -[Vn/N] => -16.

 ---<omit Volume menu, select Exit>---
 ---<omit OPT menu, select Exit>---


Design Criteria (CRIT)
--------------------
 1  WetMax;  Number of Deck Wetness/Hour
 2  AccMax;  Vertical Acceleration (Stn 4)
 3  SlmMax;  Slam Force/Displacement
 4  EffMin;  Crew Seakeeping Effectiveness
 5  OPCMin;  OPC at Endurance Speed
 6  KGmax;   Vertical Centre of Gravity
 7  Vcombat; Combat System Volume

 Enter selection  <exit> => 1

 Current Value (Default) =  60.0 (per hour)

 WetMax;  Maximum Deck Wetnesses/Hour => 30

 ---<omit CRIT menu, select Vcombat>---


 Current Value (Default) =  Vcombat/Vt = [-]0.125

 Vcombat; Combat System Volume (m3:ft3) -[Vcombat/Vt]  => 2900

 ---<omit MCI menu, select Exit>---


 ** Input complete **


 FIVPRE: enter command => all      ---<i.e. show all>---

 Title
 -----
 DESIGN OPTIMIZATION, COGAG CONFIG.

 Program Control Integers (PCI)
 ----------------------------
 MODE = Search
 Input/Output UNITS = Input: metric   Output: metric
 POST-PROCESSOR ? = Yes
 LINEPRINTER OUTPUT ? = No
 LEGEND OF ABBREVIATIONS ? = No
```

```
Primary Input (PRIM)
--------------------
                                           Minimum     Maximum     Number

DISP; Displacement (t:ton)                3500.000    4500.000       6
CrM;  Length/Displacement Ratio              7.000       9.000       5
Cp;   Prismatic Coefficient                  0.590       0.590       1
Cb;   Block Coefficient                      0.490       0.490       1
B/T;  Beam/Draft Ratio                       2.800       3.200       5

R(Ve);   Range at Endurance Speed (n.mile) =  4500.000
Wcombat; Combat System Weight (t:ton)      =   375.000
Vd;      Design Speed (kt)                 =    30.000
Vc;      Cruise Speed (kt)                 =    20.000
Ve;      Endurance Speed (kt)              =    20.000
Vw;      Seakeeping Speed (kt)             =    20.000
Hw;      Seakeeping Wave Height (m:ft)     =     5.000

 Method Control Integers (MCI)
 -----------------------------
 IDIMEN; Characteristic Dimension; Displacement
 IRESID; Residuary Resistance; NRC Fast Surface Ship series (FSS)
 IAPPND; Appendage Resistance; SHOP5 Calculations
 IPROP;  Propeller Type/OPC Values;SHOP5 Calculations, C.P. Propeller
 ISTRUC; Structure; Homogenous, same material for hull and superstructure
*IENGIN; Propulsion System; SHOP5 Engine Data Base
         Engine Selection; Must Use Selected Engine Configuration
 IGEN;   Generators; SHOP5 Diesel Generators
*IVOLUM; Volumes; Vsuper = f(Vcombat)
 ICOST;  Cost Factors; SHOP5 Cost Factors (1977 Dollars)

User-Supplied Optional Input (OPT)
----------------------------------
D;      Midship Hull Depth (m:ft) -[L/D] = 10
N;      Complement -[N/DISP^(2/3)] = -0.880
C;      Standard of Compartmentation -[Ldamage/L] = -0.150
Pgen;   Installed Generator Power (kW) -[Pgen/DISP] = 4000
dWb;    MARGIN Wb, Basic Weight (t:ton) -[dWb/Wb] = 50
dVn;    MARGIN Personnel Volume (m3:ft3) -[Vn/N] = -16

User-Supplied Design Criteria (CRIT)
------------------------------------
WetMax;  Max. Number of Deck Wetness/Hour =  30.0
Vcombat; Minimum Combat System Volume (m3:ft3) =   2900.0

Propulsion System (IENGIN); SHOP5 Engine Data Base
--------------------------
ITYPE; Type of engine configuration = COGAG
       1980 Engine Data Base

Volumes (IVOLUM); Vsuper = f(Vcombat)
----------------
VsMin; minimum Superstructure Volume = f(L,B,D,Ndeck,Pins)
VsMax/Vt; maximum Superstructure Volume/total Volume = 0.300

FIVPRE: enter command => z       ---<i.e. exit>---
```

```
** WARNING **

You have not SAVED the current file.
Exit anyway ?  <No> =>

FIVPRE: enter command => sa opt1

writing to file OPT1.....
writing to file FIVIN.....

FIVPRE: enter command => z      ---<i.e. exit>---

saving library file.....

** FIVPRE Finished **

-----------------------------------------------------------------

---<Note: lines across the page denote execution of a different
          program, accessed through the SHOP5 System Program Control
          menu; subsequent display of this menu are omitted.

** SHOP5 RUNNING, PLEASE WAIT **

---<00 min. 28 sec. CPU time, VAX 11/750>---

-----------------------------------------------------------------

FIVPOS, Post-processor for SHOP5
--------------------------------

Title: DESIGN OPTIMIZATION, COGAG CONFIG.

  8 ships generated.

reading Summary of Rejected Ships....

reading ship data....

SUMMARY OF REJECTED SHIPS
-------------------------

CONSTRAINT                   REJECTED

Deck Wetness                  16
Vertical Acceleration         28
Slam Force                    0
Seakeeping Effectiveness      0
Midship Freeboard             0
Midship Coefficient           0
OPC at Endurance Speed        0
Engines                       0
Range at Endurance Speed      63
Vertical Centre of Gravity    35
Combat System Volume          0

142 out of 150 ships were REJECTED.
```

```
    COMMAND MENU
    ------------
 1  SELECT PARAMETER
 2  Re-plot
 3  Define Window
 4  Select Ships for Lineprinter
 5  Select Ships for Transfer to FIVPRE
 6  Summary of Rejected Ships
 7  Define Terminal Type
 8  HELP
 9  EXIT

Enter selection => 1

    PARAMETER CATEGORIES
    --------------------
 1  Primary Input
 2  Dimensions and Complement
 3  Geometric Ratios and Coefficients
 4  Cost
 5  Range
 6  Weight Components
 7  Volume Components
 8  Stability
 9  Seakeeping
10  Resistance and Propulsion

Enter selection  <exit> => 5

    Range
    -----
27  R(Vd)       Range at Design Speed
28  R(Vc)       Range at Cruise Speed
29  R(Ve)       Range at Endurance Speed
30  R(M)        Mission Range
31  R(Vd)/Wf    Range at Design Speed/Fuel Weight
32  R(Vc)/Wf    Range at Cruise Speed/Fuel Weight
33  R(Ve)/Wf    Range at Endurance Speed/Fuel Weight
34  R(M)/Wf     Mission Range/Fuel Weight

Enter selection  <exit> => 27

    PARAMETER DEFINITION
    --------------------
 1  PLOT
 2  Divide By:
 3  Select Another Parameter
 4  Show Selected Parameters
 5  Reset Selected Parameters
 6  HELP

Enter selection  <exit> => 1

---<see Figure 4 in the main text>---

---<Notes: - All subsequent references to the FIVPOS menus shown
             above are omitted.
           - See Appendix E for a listing of the FIVPOS parameters.
           - Subsequent graphs for these ships are Figure 5 in the
             main text and Figures C.1 through C.3
```

```
---<on COMMAND menu, select Transfer Ships>---

SELECT SHIPS FOR TRANSFER TO FIVPRE
-----------------------------------
To select individual ships, enter each SHIP NUMBER on
a separate line.

To select a range of ships, enter two SHIP NUMBERS on
the same line, separated by a blank or comma.

Enter SHIP NUMBER(S)  <exit> => 8
Enter SHIP NUMBER(S)  <exit> =>

---<on COMMAND menu, select Exit>---

writing Summary of Rejected Ships to lineprinter.....
saving graphs for Re-Plot command.....
saving ships for FIVPRE.....

** FIVPOS Finished **

------------------------------------------------------------------


FIVPRE, Pre-processor for SHOP5
-------------------------------

reading library file.....

reading ships from FIVPOS.....

Primary Input (PRIM), Geometry      ---<automatic display>---
------------------------------
Disp  4500.0
CrM      8.50
Cp     0.590
Cb     0.490
B/T    3.200

FIVPRE: enter command => c mode      ---<i.e. CHANGE MODE>---

   MODE
   ----
0  SEARCH
1  DESCRIBE

MODE ?  <SEARCH> =>

   Mode Change: DESCRIBE to SEARCH
   ----------------------------
1  Restore most recent SEARCH mode file
2  Select DESCRIBE mode ship to initialize search space
3  Define search space from scratch.
4  Cancel mode-change

Enter selection  <Restore SEARCH> => 2

Rv(e);   Range at Endurance Speed => 4500
```

```
Primary Input (PRIM)
--------------------
                                         Minimum      Maximum      Number

DISP; Displacement (t:ton)              4500.000     4500.000        1
CrM;  Length/Displacement Ratio            8.500        8.500        1
Cp;   Prismatic Coefficient                0.590        0.590        1
Cb;   Block Coefficient                    0.490        0.490        1
B/T;  Beam/Draft Ratio                     3.200        3.200        1

R(Ve);   Range at Endurance Speed (n.mile) =   4500.000
Wcombat; Combat System Weight (t:ton)      =    375.000
Vd;      Design Speed (kt)                 =     30.000
Vc;      Cruise Speed (kt)                 =     20.000
Ve;      Endurance Speed (kt)              =     20.000
Vw;      Seakeeping Speed (kt)             =     20.000
Hw;      Seakeeping Wave Height (m:ft)     =      5.000

FIVPRE: enter command => c crm
                                         Minimum      Maximum      Number

 CrM; Length/Displacement Ratio           8.500        8.500         1

 CrM; Length/Displacement Ratio      Minimum => 8
                                     Maximum => 8.5
                              Number of values => 6

FIVPRE: enter command => c cp
                                         Minimum      Maximum      Number

 Cp; Prismatic Coefficient                0.590        0.590         1

 Cp; Prismatic Coefficient           Minimum => .57
                                     Maximum => .61
                              Number of values => 3

FIVPRE: enter command => c cb
                                         Minimum      Maximum      Number

 Cb; Block Coefficient                    0.490        0.490         1

 Cb; Block Coefficient               Minimum => .47
                                     Maximum => .51
                              Number of values => 3

FIVPRE: enter command => c b/t
                                         Minimum      Maximum      Number

 B/T; Beam/Draft Ratio                    3.200        3.200         1

 B/T; Beam/Draft Ratio               Minimum => 2.8
                                     Maximum => 3.2
                              Number of values => 5

FIVPRE: enter command => sa      ---<i.e. SAVE>---

Enter FILE NAME  <FIVIN only> =>

writing to file FIVIN.....
```

```
FIVPRE: enter command => z

saving library file.....

** FIVPRE Finished **

-------------------------------------------------------------------

** SHOP5 RUNNING, PLEASE WAIT **

---<00 min. 57 sec CPU time, VAX 11/750>---

-------------------------------------------------------------------

FIVPOS, Post-processor for SHOP5
--------------------------------

Title: DESIGN OPTIMIZATION, COGAG CONFIG.

105 ships generated.

reading Summary of Rejected Ships....

reading ship data....  10  20  30  40  50  60  70  80  90 100

SUMMARY OF REJECTED SHIPS
-------------------------

CONSTRAINT                  REJECTED

Deck Wetness                   0
Vertical Acceleration          0
Slam Force                     0
Seakeeping Effectiveness       0
Midship Freeboard              0
Midship Coefficient           90
OPC at Endurance Speed         0
Engines                        0
Range at Endurance Speed       0
Vertical Centre of Gravity    75
Combat System Volume           0

165 out of 270 ships were REJECTED.

    COMMAND MENU
    ------------
 1  SELECT PARAMETER
 2  Re-plot
 3  Define Window
 4  Select Ships for Lineprinter
 5  Select Ships for Transfer to FIVPRE
 6  Summary of Rejected Ships
 7  Define Terminal Type
 8  HELP
 9  EXIT

Enter selection => 2      ---<i.e. Re-Plot>---
```

```
                 Parameter(s)

 1  FC(Vc)       Fuel Consumption, Cruise Speed
 2  Vsuper       Superstructure Volume
 3  CrM          Length/Displacement Ratio (Circle M)
 4  P.A. $       Platform Acquisition Cost (lead ship)
 5  R(Vd)        Range at Design Speed
 6  GM/B         Metacentric Height/Beam
 7  Pins         Total Installed Power
 8  Vmax(w)      Maximum Speed in Waves (limited by Pins only)
 9  R(Ve)        Range at Endurance Speed
10  KG/KGmax     KG/maximum KG for Damaged Stability
11  ..ratio      (Vsuper) / (Vtotal)
12  B/T          Beam/Draft Ratio
13  Cb           Block Coefficient
14  Cp           Prismatic Coefficient
15  DISP         Displacement

Enter selection  <exit> => 5

---<see Figure C.4>---
---<on COMMAND menu, select Define Window>---

WINDOW DEFINITION
-----------------
The window is defined by low and high ship numbers,
corresponding to left and right sides of the window.

The window definition is preserved until reset.

Enter SHIP NUMBER: LOW  => 81,99

---<on COMMAND menu, select Re-Plot>---
---<on Re-Plot menu, select item 1 (most recent plot)>---
---<see Figure 7 in main text>---
---<on COMMAND menu, select Transfer Ships>---

SELECT SHIPS FOR TRANSFER TO FIVPRE
-----------------------------------
To select individual ships, enter each SHIP NUMBER on
a separate line.

To select a range of ships, enter two SHIP NUMBERS on
the same line, separated by a blank or comma.

Enter SHIP NUMBER(S)  <exit> => 90,92
Enter SHIP NUMBER(S)  <exit> =>

---<on COMMAND menu, select Exit, omit exit messages>---

** FIVPOS Finished **

-------------------------------------------------------------------

FIVPRE, Pre-processor for SHOP5
-------------------------------

reading library file.....
reading ships from FIVPOS.....
```

```
Primary Input (PRIM), Geometry      ---<automatic display>---
-----------------------------

SHIP      1      2      3
        [90]   [91]   [92]

Disp  4500.0 4500.0 4500.0
CrM     8.40   8.40   8.50
Cp     0.610  0.610  0.570
Cb     0.490  0.510  0.470
B/T    3.200  3.200  3.200

FIVPRE: enter command => c mode

   MODE
   ----
0  SEARCH
1  DESCRIBE

MODE ?  <SEARCH> =>        ---<i.e. Return only = SEARCH mode>---

   Mode Change: DESCRIBE to SEARCH
   ------------------------------

1  Restore most recent SEARCH mode file
2  Select DESCRIBE mode ship to initialize search space
3  Define search space from scratch.
4  Cancel mode-change

Enter selection  <Restore SEARCH> => 2

Which ship ?  Enter SHIP NUMBER or ?  <exit> => 2

Rv(e);   Range at Endurance Speed => 4500

Primary Input (PRIM)      ---<automatic display>---
--------------------
                                      Minimum    Maximum     Number

DISP; Displacement (t:ton)           4500.000   4500.000       1
CrM;  Length/Displacement Ratio         8.400      8.400       1
Cp;   Prismatic Coefficient             0.610      0.610       1
Cb;   Block Coefficient                 0.510      0.510       1
B/T;  Beam/Draft Ratio                  3.200      3.200       1

R(Ve);   Range at Endurance Speed (n.mile) =   4500.000
Wcombat; Combat System Weight (t:ton)      =    375.000
Vd;      Design Speed (kt)                 =     30.000
Vc;      Cruise Speed (kt)                 =     20.000
Ve;      Endurance Speed (kt)              =     20.000
Vw;      Seakeeping Speed (kt)             =     20.000
Hw;      Seakeeping Wave Height (m:ft)     =      5.000

FIVPRE: enter command => c crm

---<omit re-definition of Primary Input, new values shown below>---
```

		Minimum	Maximum	Number
DISP;	Displacement (t:ton)	4520.000	4560.000	3
CrM;	Length/Displacement Ratio	8.350	8.450	3
Cp;	Prismatic Coefficient	0.590	0.620	3
Cb;	Block Coefficient	0.500	0.520	3
B/T;	Beam/Draft Ratio	3.100	3.300	3

FIVPRE: enter command => sa ---<i.e. SAVE>---

Enter FILE NAME <FIVIN only> =>

writing to file FIVIN.....

FIVPRE: enter command => z

** FIVPRE Finished **

** SHOP5 RUNNING, PLEASE WAIT **

---<00 min. 54 sec. CPU time, VAX 11/750>---

FIVPOS, Post-processor for SHOP5

Title: DESIGN OPTIMIZATION, COGAG CONFIG.

129 ships generated.

reading Summary of Rejected Ships....

reading ship data.... 10 20 30 40 50 60 70 80 90 100
110 120

SUMMARY OF REJECTED SHIPS

CONSTRAINT	REJECTED
Deck Wetness	0
Vertical Acceleration	0
Slam Force	0
Seakeeping Effectiveness	0
Midship Freeboard	0
Midship Coefficient	81
OPC at Endurance Speed	0
Engines	0
Range at Endurance Speed	0
Vertical Centre of Gravity	33
Combat System Volume	0

114 out of 243 ships were REJECTED.

---<End of Appendix C>---

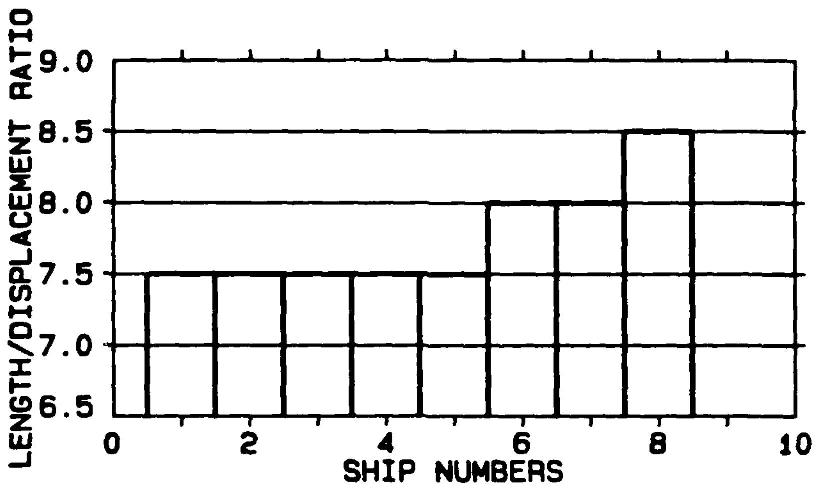

Figure C.1: Length Displacement Ratio, First-Run Ships

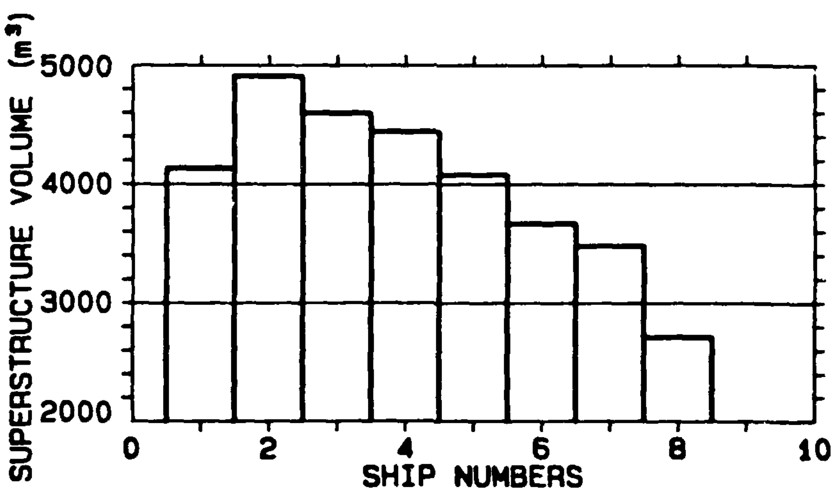

Figure C.2: Superstructure Volume, First-Run Ships

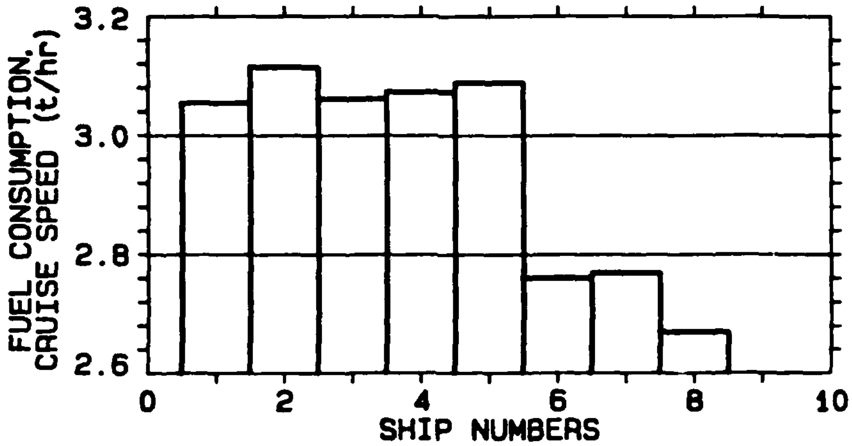

Figure C.3: Fuel Consumption at Cruise Speed, First-Run Ships

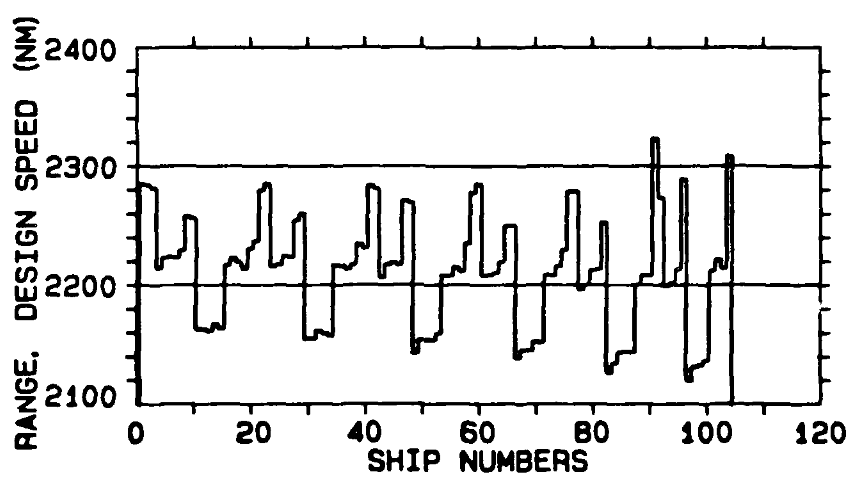

Figure C.4: Range at Design Speed, Second-Run Ships

Appendix D: Design Optimization Example, Session 2

The trends shown in Appendix C lead towards the design candidate selected in this appendix. The relative merits of this ship are illustrated by examining FIVPOS graphics and lineprinter output. The SHOP5 DESCRIBE mode lineprinter output for this ship is also included.

This terminal session is presented using the same format as Appendix C.

```
 FIVPOS, Post-processor for SHOP5
 --------------------------------

 Title: DESIGN OPTIMIZATION, COGAG CONFIG.

  83 ships generated.

 reading Summary of Rejected Ships....

reading ship data....  10  20  30  40  50  60  70  80

 SUMMARY OF REJECTED SHIPS
 -------------------------

 CONSTRAINT                    REJECTED

 Deck Wetness                     0
 Vertical Acceleration            0
 Slam Force                       0
 Seakeeping Effectiveness         0
 Midship Freeboard                0
 Midship Coefficient             54
 OPC at Endurance Speed           0
 Engines                          0
 Range at Endurance Speed         0
 Vertical Centre of Gravity      79
 Combat System Volume             0

 133 out of 216 ships were REJECTED.

     COMMAND MENU
     ------------
  1  SELECT PARAMETER
  2  Re-plot
  3  Define Window
  4  Select Ships for Lineprinter
  5  Select Ships for Transfer to FIVPRE
  6  Summary of Rejected Ships
  7  Define Terminal Type
  8  HELP
  9  EXIT

 Enter selection => 2
```

Parameter(s)

1	P.A. $	Platform Acquisition Cost (lead ship)
2	CrM	Length/Displacement Ratio (Circle M)
3	GM/B	Metacentric Height/Beam
4	R(Vd)	Range at Design Speed
5	FC(Vc)	Fuel Consumption, Cruise Speed
6	Vsuper	Superstructure Volume
7	Pins	Total Installed Power
8	Vmax(w)	Maximum Speed in Waves (limited by Pins only)
9	R(Ve)	Range at Endurance Speed
10	KG/KGmax	KG/maximum KG for Damaged Stability
11	..ratio	(Vsuper) / (Vtotal)
12	B/T	Beam/Draft Ratio
13	Cb	Block Coefficient
14	Cp	Prismatic Coefficient
15	DISP	Displacement

Enter selection <exit> => 4

---<see Figure D.1>---
---<Define Window for ships 61 to 79 and then Re-Plot>---
---<see Figure D.2>---
---<Transfer Ships 69, 70 and 71 to FIVPRE>---
---<Exit from FIVPOS, omit exit messages>---

FIVPRE, Pre-processor for SHOP5

reading library file.....
reading ships from FIVPOS.....

Primary Input (PRIM), Geometry ---<automatic display>---

SHIP	1 [69]	2 [70]	3 [71]
Disp	4620.0	4620.0	4620.0
CrM	8.35	8.35	8.35
Cp	0.595	0.595	0.595
Cb	0.505	0.505	0.505
B/T	3.150	3.150	3.150

FIVPRE: enter command => c mode

---<omit re-definition of Primary Input, new values shown below>---

	Minimum	Maximum	Number
DISP; Displacement (t:ton)	4620.000	4620.000	1
CrM; Length/Displacement Ratio	8.350	8.450	3
Cp; Prismatic Coefficient	0.585	0.595	3
Cb; Block Coefficient	0.495	0.505	3
B/T; Beam/Draft Ratio	2.950	3.250	7

```
FIVPRE: enter command => sa       ---<i.e. SAVE>---

---<omit SAVE and EXIT from FIVPRE>---

------------------------------------------------------------------

** SHOP5 RUNNING, PLEASE WAIT **

---<00 min. 39 sec CPU time, VAX 11/750>---

------------------------------------------------------------------

FIVPOS, Post-processor for SHOP5
--------------------------------

Title: LONG COGAG

 58 ships generated.

reading Summary of Rejected Ships....

reading ship data....  10  20  30  40  50

SUMMARY OF REJECTED SHIPS
-------------------------

CONSTRAINT                    REJECTED

Deck Wetness                    0
Vertical Acceleration           0
Slam Force                      0
Seakeeping Effectiveness        0
Midship Freeboard               0
Midship Coefficient            63
OPC at Endurance Speed          0
Engines                         0
Range at Endurance Speed        0
Vertical Centre of Gravity     68
Combat System Volume            0

131 out of 189 ships were REJECTED.

---<omit FIVPOS menus>---
---<see Figure 7 in main text and Figures D.4 through D.7>---
---<select ships 18 to 24 for lineprinter output, see Table D.1>---
---<select ship 20 for transfer to FIVPRE>---
---<omit Exit from FIVPOS>---

-------------------------------------------------------------------

FIVPRE, Pre-processor for SHOP5
-------------------------------

reading library file.....

reading ships from FIVPOS.....
```

```
Primary Input (PRIM), Geometry        ---<automatic display>---
------------------------------

Disp  4620.0
CrM      8.35
Cp      0.595
Cb      0.505
B/T     3.150

FIVPRE: enter command => c tit        ---<i.e. CHANGE TITLE>---

Enter TITLE => long cogag

FIVPRE: enter command => sa s1        --<i.e. SAVE (as file) S1>---

writing to file S1.....
writing to file FIVIN.....

FIVPRE: enter command => z

saving library file.....

** FIVPRE Finished **

--------------------------------------------------------------------

** SHOP5 RUNNING, PLEASE WAIT **

---<00 min. 05 sec CPU time>---

--------------------------------------------------------------------


---<see Table D.2 for SHOP5 DESCRIBE mode ouput on this ship>---

                ---<End of Appendix D>---
```

Table D.1: FIVPOS LINEPRINTER OUTPUT FOR SHIPS 18 THROUGH 24

FIVPOS
SHOP5 POST-PROCESSOR

14:09:08 29-JAN-88

LONG COGAG

		REJECTION CRITERIA VIOLATIONS										
DISP TONNE	CrM	WetMax 1	AccMax 2	SlmMax 3	EffMin 4	FmMin 5	CmMax 6	OPCmin 7	ENGINE 8	RANGE 9	KGmax 10	Vcombat 11
4620.0	8.35	0	0	0	0	0	21	0	0	0	20	0
	8.40	0	0	0	0	0	21	0	0	0	22	0
	8.45	0	0	0	0	0	21	0	0	0	26	0

SUMMARY OF REJECTED SHIPS

CRITERIA	REJECTS
WetLim	0
AccLim	0
SlmLim	0
EffLim	0
Fm Lim	0
Cm Lim	63
OPCLim	0
ENGINE	0
RANGE	0
KGmLim	68
VolLim	0

REJECTION CRITERIA

NUMBER	NAME	SHIP REJECTED WHEN CONDITION TRUE	LIMIT VALUE
1	WetLim	NUMBER OF DECK WETNESSES PER HOUR > LIMIT	30.
2	AccLim	VERTICAL ACCELERATION AT STATION 4 / G > LIMIT	0.200
3	SlmLim	SLAM FORCE / DISPLACEMENT > LIMIT	0.200
4	EffLim	SEAKEEPING EFFECTIVENESS < LIMIT	50.
5	Fm Lim	MIDSHIP FREEBOARD < FREEBOARD FOR RESERVE BUOYANCY	
6	Cm Lim	MIDSHIP COEFFICIENT OUTSIDE OF RESISTANCE SERIES RANGE	
7	OPCLim	PROPULSIVE EFFICIENCY AT ENDURANCE SPEED < LIMIT	0.600
8	ENGINE	SATISFACTORY ENGINE CONFIGURATION NOT FOUND	
9	RANGE	RANGE AT ENDURANCE SPEED < MINIMUM ACCEPTABLE RANGE	4500.
10	KGmLim	VERTICAL CENTRE OF GRAVITY > DAMAGED STABILITY CRITERIA	
11	VolLim	COMBAT SYSTEM VOLUME < LIMIT (FT**3:M**3)	2900.

	SHIP NUMBERS =>		18	19	20	21	22	23	24
DIMENSIONS	Displacement	t	4620.000	4620.000	4620.000	4620.000	4620.000	4620.000	4620.000
	Length	m	137.922	137.922	137.922	137.922	137.922	138.748	138.748
	Beam	m	14.461	14.573	14.276	14.389	14.501	14.377	14.490
	Draft	m	4.519	4.484	4.532	4.497	4.462	4.564	4.528
	Hull Depth	m	10.000	10.000	10.000	10.000	10.000	10.000	10.000
	Wetted Surface	m**2	2058.971	2063.262	2029.649	2035.175	2040.702	2057.309	2061.600
HULL FORM	Circle M		8.350	8.350	8.350	8.350	8.350	8.400	8.400
	Cp		0.595	0.595	0.595	0.595	0.595	0.585	0.585
	Cb		0.500	0.500	0.505	0.505	0.505	0.495	0.495
	B/T		3.200	3.250	3.150	3.200	3.250	3.150	3.200
WEIGHTS	Structure	t	1629.935	1625.827	1629.774	1625.576	1621.482	1633.754	1629.538
	Propulsion	t	397.594	397.594	397.594	397.594	397.594	397.594	397.594
	Electrical	t	244.941	244.941	244.941	244.941	244.941	244.941	244.941
	Auxiliary	t	472.773	473.566	471.688	472.490	473.280	472.154	472.960
	Outfit/Furnish.	t	355.807	355.807	355.807	355.807	355.807	355.807	355.807
	Disposable Loads	t	196.474	196.601	196.522	196.652	196.779	196.351	196.482
	Fuel	t	897.477	900.664	898.675	901.941	905.117	894.400	897.679
	Combat Systems	t	375.000	375.000	375.000	375.000	375.000	375.000	375.000
VOLUMES	TOTAL	m**3	16866.951	16912.273	16805.227	16850.813	16895.918	16831.711	16877.600
	SUPERSTRUCTURE	m**3	2950.445	2862.158	3031.096	2942.694	2854.854	3077.901	2989.312
	HULL	m**3	13916.506	14050.115	13774.131	13908.119	14041.064	13753.811	13888.288
	Machinery	m**3	3779.379	3818.438	3715.300	3754.469	3793.335	3750.182	3789.628
	Personnel	m**3	3872.000	3872.000	3872.000	3872.000	3872.000	3872.000	3872.000
	Outfit/Systems	m**3	5150.294	5152.418	5151.093	5153.269	5155.384	5148.245	5150.430
	Fuel	m**3	1165.277	1169.416	1166.833	1171.073	1175.197	1161.283	1165.540
	Combat Systems	m**3	2900.000	2900.001	2900.000	2900.001	2900.000	2900.000	2900.002
DESIGN SPEED	Resistance	t	134.812	134.965	128.063	128.319	128.578	133.470	133.618
	OPC		0.624	0.622	0.628	0.626	0.625	0.626	0.625
	Fuel Consumption	t/hr	10.081	10.103	9.701	9.727	9.751	9.987	10.005
	Range	n.mile	2416.324	2419.758	2514.399	2516.929	2519.588	2430.880	2435.367
CRUISE SPEED	Resistance	t	44.915	44.990	42.136	42.257	42.380	44.030	44.103
	OPC		0.642	0.641	0.644	0.643	0.643	0.643	0.643
	Fuel Consumption	t/hr	2.825	2.830	2.712	2.718	2.725	2.781	2.786
	Range	n.mile	5749.111	5759.081	5996.524	6004.309	6011.079	5818.635	5830.550
ENDURANCE SPEED	Resistance	t	44.915	44.990	42.136	42.257	42.380	44.030	44.103
	OPC		0.642	0.641	0.644	0.643	0.643	0.643	0.643
	Fuel Consumption	t/hr	2.825	2.830	2.712	2.718	2.725	2.781	2.786
	Range	n.mile	5749.111	5759.081	5996.524	6004.309	6011.079	5818.635	5830.550
MISSION	Range	n.mile	5222.083	5230.879	5444.792	5451.608	5457.693	5280.197	5290.839
	Transport Eff.		0.051	0.052	0.049	0.049	0.049	0.051	0.051
	Specific Power		1.448	1.444	1.525	1.519	1.514	1.466	1.463
ENGINES	Max. Speed	knots	31.359	31.336	31.769	31.740	31.714	31.458	31.439
	Installed Power	kW	46848.801	46848.801	46848.801	46848.801	46848.801	46848.801	46848.801
	Main Engines	kW	18650.000	18650.000	18650.000	18650.000	18650.000	18650.000	18650.000
	Cruise Engines	kW	4774.400	4774.400	4774.400	4774.400	4774.400	4774.400	4774.400
	Configuration		COGAG	COGAG	COGAG	COGAG	COGAG	COGAG	COGAG
STABILITY	GM	m	1.648	1.743	1.471	1.564	1.657	1.518	1.611
	GMf	m	1.483	1.578	1.305	1.398	1.492	1.352	1.445
	KG	m	5.516	5.504	5.525	5.512	5.500	5.533	5.520
	KGmax	m	5.641	5.687	5.530	5.574	5.620	5.544	5.588
SEAKEEPING	Deck Wetness	per hour	7.116	6.986	7.410	7.270	7.137	6.864	6.735
	Vertical Accn/g		0.166	0.165	0.167	0.166	0.166	0.165	0.164
	Slam Force/Disp.		0.059	0.061	0.062	0.064	0.067	0.044	0.046
	Effectiveness	percent	67.796	68.081	67.255	67.556	67.846	68.201	68.493
	Complement	person	242.000	242.000	242.000	242.000	242.000	242.000	242.000
	P.A. Cost (lead)	M$	237.107	237.088	237.043	237.023	237.004	237.149	237.129

TABLE D.2: SHOP5 LINEPRINTER OUTPUT FOR SHIP 20

```
                SHOP5
      DREA CONCEPT EXPLORATION MODEL
   FOR MONOHULL FRIGATES AND DESTROYERS

     14:08:08            29-JAN-88

   LONG COGAG

   MODE   = 1   INOUT = 3   IPOST = 0   ILPT   = 1
   ILEGND= 0    NCON  = 2   NOPTN = 6   NLIM   = 2

           DESCRIBE MODE
           -------------
             1 SHIP
```

INDEPENDENT VARIABLES						REQUIREMENTS				
DISP t	CIRCLE M	Cp	Cb	B/T	Wcombat t	Vd KTS	Vc KTS	Ve KTS	Vw KTS	Hw m
4620.00	8.35	0.595	0.505	3.15	375.0	30.0	20.0	20.0	20.0	5.00

METHOD CONTROL INTEGERS FOR CURRENT EXECUTION

NUMBER	NAME	VALUE	DESCRIPTION
1	IDIMEN	0	CHARACTERISTIC DIMENSION = DISPLACEMENT
2	IRESID	0	RESIDUARY RESISTANCE: NRC FSS SERIES
3	IAPPND	0	SHOP5 APPENDAGE RESISTANCE CALCULATIONS
4	IPROP	0	SHOP5 OPC CALCULATIONS, C.P. PROPELLER
5	ISTRUC	0	HOMOGENEOUS HULL AND SUPERSTRUCTURE
* 6	IENGIN	2	SHOP5 ENGINE DATA BASE
7	ICHOOS	0	MUST USE SELECTED ENGINE CONFIGURATION
8	IGEN	0	SHOP5 DIESEL GENERATORS
* 9	IVOLUM	1	SUPERSTRUCTURE VOLUME: Vsuper = f(Vcombat)
10	ICOST	0	SHOP5 COST CALCULATIONS (1977 DOLLARS)

SEAKEEPING CRITERIA :   WetMax =   30.   AccMax = 0.200   SlmMax = 0.200   EffMin =   50.

COMBAT SYSTEM VOLUME: Vcombat =   2900.00   m3

OPTIONAL INPUT: VALUES FOR CURRENT CALCULATIONS

NUMBER	NAME	VALUE	DESCRIPTION	UNITS
* 1	D	10.0000	MIDSHIP HULL DEPTH	m
2	Cw	0.695 Cp + 0.335	WATERPLANE COEFFICIENT	
3	LCB	LCB/L = 0.515	LONGITUDINAL CENTRE OF BUOYANCY	
4	LCF	LCF/L = 0.557	LONGITUDINAL CENTRE OF FLOTATION	
* 5	N	N/DISP^2/3 =0.8800	COMPLEMENT (Accomodations)	
6	Ndeck	D/2.59 - 1	NUMBER OF INTERNAL DECKS	
7	Nbulk	f(L,L/B)	NUMBER OF WATERTIGHT BULKHEADS	
* 8	C	DAMAGE/L = 0.1500	FRACTION OF SHIP LENGTH OPEN TO FLOODING	
9	Lsuper	Lsuper/L = 0.55	SUPERSTRUCTURE LENGTH	m
10	Ffp	Ffp/L = f(L)	FREEBOARD AT FORWARD PERPENDICULAR	m
11	Tos	NORTH ATLANTIC	WAVE MODAL PERIOD FOR SEAKEEPING	sec
12	AccHi	AccHi = 0.05 (g)	VERTICAL ACCELERATION/g, 0% CREW EFFECTIVENESS	m/sec2
13	AccLo	AccLo = 0.25 (g)	VERTICAL ACCELERATION/g, 100% CREW EFFECTIVENESS	m/sec2
14	Ca	0.0005	MODEL-SHIP CORRELATION ALLOWANCE	
15	dPe	0.10	MARGIN ON EFFECTIVE POWER, Pe=(1+dPe)R*V	
16	DIAM	DIAM/T = 1.0	PROPELLER DIAMETER	m
17	Nshaft	2	NUMBER OF PROPELLER SHAFTS	
18	Ngen	4	NUMBER OF ELECTRICAL GENERATORS	
* 19	Pgen	4000.0000	ELECTRICAL POWER INSTALLED	kW
20	avPgen	avPgen = Pgen/4	AVERAGE ELECTRICAL POWER FOR RANGE	kW
21	Hwr	3.00	SIGNIFICANT WAVE HEIGHT FOR RANGE	m
22	Tor	NORTH ATLANTIC	WAVE MODAL PERIOD FOR RANGE	sec
23	YIELD	2.835	YIELD STRENGTH OF HULL MATERIAL	t/cm2
24	DENS	7.858	DENSITY OF HULL MATERIAL	t/m3
25	Fmod	1.0	FACTOR FOR STRUCTURAL MODULUS	
26	RAFT	0.0	MARGIN: MAIN ENGINE RAFTING	t
27	GEAR	0.0	MARGIN: on W2 for GEAR BOX WEIGHT	t
28	dW1	0.0	MARGIN: on W1 (HULL STRUCTURE)	t
29	dW2	0.0	MARGIN: on W2 (PROPULSION MACHINERY)	t
30	dW3	0.0	MARGIN: on W3 (ELECTRICAL)	t
31	dW5	0.0	MARGIN: on W5 (AUXILIARIES)	t
32	dW6	0.0	MARGIN: on W6 (OUTFIT & FURNISHING)	t
* 33	dWb	50.0000	MARGIN: on Wbasic (BASIC WEIGHT)	t
34	dWd	0.0	MARGIN: on Wd (DISPOSABLE LOADS WEIGHT)	t
35	KGb	KGb/D = 0.65	VCG OF EXTRA BASIC WEIGHT	m
36	KGc	KGc/D = 1.00	VCG OF COMBAT SYSTEM WEIGHT	m
37	Vsuper	Calculated	SUPERSTRUCTURE SIZED FOR COMBAT SYSTEMS	m3
38	dVm	0.0	MARGIN: on Vm (MACHINERY VOLUME)	m3
39	dVo	0.0	MARGIN: on Vo (SYSTEMS AND OUTFIT VOLUME)	m3
40	dVb	0.0	MARGIN: Vbasic (BASIC VOLUME)	m3
* 41	Vn/N	Vn/N = 16.00	VOLUME PER PERSON	m3/prsn
42	Td/T	0.05	NORMALIZED TIME AT DESIGN SPEED	
43	Tc/T	0.30	NORMALIZED TIME AT CRUISE SPEED	
44	Te/T	0.65	NORMALIZED TIME AT ENDURANCE SPEED	

```
INPUT RECORD (10): PROPULSION SYSTEM
  CONFIGURATION = COGAG
  1980 ENGINES
  MUST USE SELECTED ENGINE CONFIGURATION

INPUT RECORD (12): SUPERSTRUCTURE VOLUME CONSTRAINTS
  Vsmin: minimum Superstructure Volume = calculated.
  Vsmax/Vt: maximum Superstructure Volume/total Volume = 0.3000
```

***** SHIP NUMBER 1 *****

GENERAL			FORM COEFFICIENTS		MISCELLANEOUS	
DISPLACEMENT =	4620.00	t		Cb = 0.505	N = 242	Lsuper = 75.9 m
LENGTH =	137.92	m	CrM = 8.350	Cp = 0.595	Ndeck = 2.9	
BEAM =	14.28	m	L/B = 9.661	Cm = 0.849	Nbulk = 16	
DRAFT =	4.53	m	B/T = 3.150	Cw = 0.749	SIGMA = 1.36	Pgen = 4000. kW
FREEBOARD =	5.47	m		Cvp = 0.675	Kt/J2 = 0.174	avPgen = 1000. kW
DEPTH =	*10.00*	*m*	L/D = 13.792	Cit = 0.0476	J = 1.09	SFCgen = 0.249 kg/kW-HR
WETTED AREA =	2029.6	m2	CRS = 7.560	Cv = 0.00172	RPM = 173.3	Pins = 46849. kW
VOLUME DISP. =	4506.5	m3	DLR = 49.076	Cs = 2.574	ITYPE = 2	DIAM = 4.53 m

CALM WATER RESISTANCE AND PROPULSION

SPEED KTS	FROUDE NUMBER	RESISTANCE FRICTIONAL t	RESISTANCE RESIDUARY t	RESISTANCE APPENDAGE t	RESISTANCE TOTAL t	EFFECTIVE POWER kW	OPC	REQUIRED POWER kW	FUEL CONSUMPT. t/hr	RANGE CALM N.MILES
30.0	0.42	48.76	59.83	19.47	128.06	21343.	0.628	33998.	9.077	2687.
20.0	0.28	22.48	10.70	8.96	42.14	4682.	0.644	7271.	2.401	6773.

POWERING IN WAVES, Hwr = 3.00 m , Tor = 10.03 sec

SPEED KTS	FROUDE NUMBER	ADDED POWER kW	REQUIRED POWER kW	FUEL CONSUMPT. t/hr	RANGE WAVES N.MILES
30.0	0.42	3257.	37256.	9.701	2514.
20.0	0.28	1364.	8635.	2.712	5997.

WEIGHTS t			VOLUMES m3			STABILITY m	SEAKEEPING m	MISSION	COST M$
W1	= 1629.77	= 0.353	Vhull =	13774.	= 0.820	GM = 1.47	Hw = 5.00	Td/T = 0.050	C1 = 6.9
W2	= 397.59	= 0.086	Vsuper =	3031.	= 0.180	GMf = 1.31	Tos = 12.07	Tc/T = 0.300	C2 = 22.4
W3	= 244.94	= 0.053					Vw = 20.00	Te/T = 0.650	C3 = 11.9
W5	= 471.69	= 0.102	Vm =	3715.	= 0.221	KB = 2.76	Nwet = 7.		C4 = 12.1
W6	= 355.81	= 0.077	Vo =	5151.	= 0.307	BM = 4.24	Accn = 0.167	Vmsn = 20.50	C5 = 7.0
dWb	= 50.00	= 0.011	dVb =	0.	= 0.000	KG = 5.53	Fslam = 0.062	Rmsn = 6095.3	C6 = 60.3
Wbasic	= 3149.80	= 0.682	Vbasic =	8866.	= 0.528	KGmax= 5.53	S EFF = 67.3	Rmsnw = 5444.8	C7L = 90.6
Wloads	= 1470.20	= 0.318	Vloads =	7939.	= 0.472	KGc = 10.00	Ffp = 8.83	Teff = 1.525	C7C = 45.3
Wcombat	= 375.00	= 0.081	Vcombat=	2900.	= 0.173	Erb = 1.38	Vwet = 30.00	SP = 0.049	C8 = 4.1
Wd	= 196.52	= 0.043	Vn =	3872.	= 0.230	TAU = 10.12	Vaccn = 24.63	Vmax = 32.50	C9L = 178.2
Wf	= 898.67	= 0.195	Vf =	1167.	= 0.069		Vslam = 25.40	Vmaxw = 31.77	C9C = 126.1
							Veff = 26.99		C10L = 237.0
TOTAL	= 4620.00	= 1.000	TOTAL =	16805.	= 1.000				C10C = 162.7

COGAG	ENGINE CONFIGURATION PER SHAFT	TYPE	INSTALLED POWER kW	REQUIRED POWER kW	SPECIFIC FUEL CON. kg/kW-HR	WEIGHT t
CRUISE	DDA 570	TURBINE	4774.	4317.	0.285	2.3
MAIN	LM 2500	TURBINE	18650.	13854.	0.245	15.6

TABLE OF RESISTANCE, POWER, AND RANGE

	CALM WATER							WAVES : HWR = 3.00, TOR = 10.03			
SPEED KTS	FROUDE NUMBER	TOTAL RESISTANCE t	EFFECTIVE POWER kW	OPC	REQUIRED POWER kW	FUEL CONSUMPT. t/hr	RANGE CALM N MILES	ADDED POWER kW	REQUIRED POWER kW	FUEL CONSUMPT. t/hr	RANGE WAVES N MILES
10.0	0.140	9.10	506.	0.646	783.	0.921	8824.	356.	1139.	1.003	8110.
11.0	0.154	11.01	673.	0.646	1041.	0.980	9124.	404.	1444.	1.072	8341.
12.0	0.168	13.10	873.	0.646	1351.	1.051	9283.	461.	1812.	1.156	8439.
13.0	0.182	15.39	1111.	0.646	1719.	1.135	9313.	530.	2249.	1.256	8417.
14.0	0.196	17.87	1390.	0.646	2151.	1.233	9230.	610.	2761.	1.372	8294.
15.0	0.210	20.77	1730.	0.646	2678.	1.354	9010.	704.	3382.	1.514	8055.
16.0	0.224	24.02	2135.	0.646	3306.	1.497	8692.	810.	4116.	1.681	7737.
17.0	0.238	27.58	2604.	0.646	4033.	1.663	8313.	930.	4963.	1.875	7374.
18.0	0.252	31.55	3154.	0.645	4888.	1.857	7879.	1062.	5950.	2.100	6971.
19.0	0.266	36.58	3861.	0.645	5990.	2.109	7326.	1207.	7197.	2.384	6480.
20.0	0.280	42.14	4682.	0.644	7271.	2.401	6773.	1364.	8635.	2.712	5997.
21.0	0.294	48.23	5626.	0.643	8751.	2.738	6235.	1532.	10284.	4.535	3765.
22.0	0.308	54.08	6610.	0.642	10292.	4.537	3943.	1710.	12002.	4.864	3677.
23.0	0.322	59.71	7629.	0.642	11887.	4.842	3862.	1896.	13783.	5.205	3593.
24.0	0.336	65.68	8757.	0.641	13655.	5.181	3767.	2089.	15744.	5.581	3496.
25.0	0.350	71.99	9998.	0.641	15609.	5.555	3659.	2286.	17896.	5.993	3392.
26.0	0.364	81.46	11765.	0.639	18426.	6.095	3469.	2486.	20912.	6.571	3217.
27.0	0.378	91.73	13759.	0.636	21640.	6.710	3272.	2686.	24326.	7.225	3039.
28.0	0.392	102.85	15998.	0.633	25256.	7.403	3075.	2884.	28139.	7.955	2862.
29.0	0.406	114.93	18516.	0.631	29355.	8.188	2880.	3075.	32430.	8.777	2687.
30.0	0.420	128.06	21343.	0.628	33998.	9.077	2687.	3257.	37256.	9.701	2514.

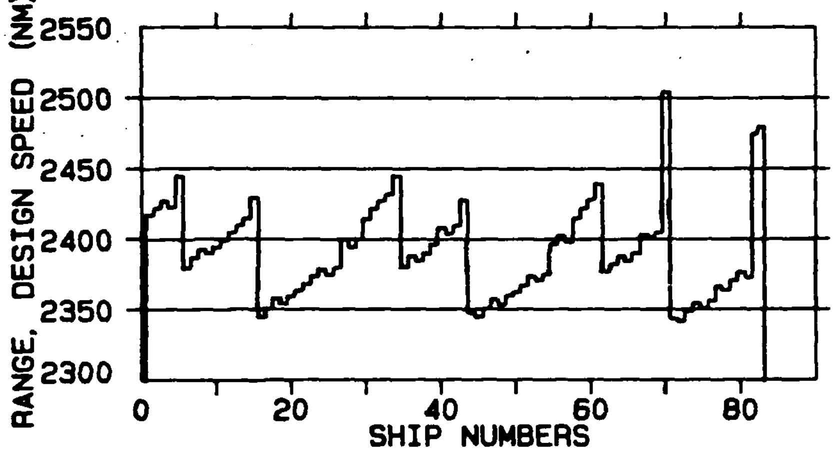

Figure D.1: Range at Design Speed

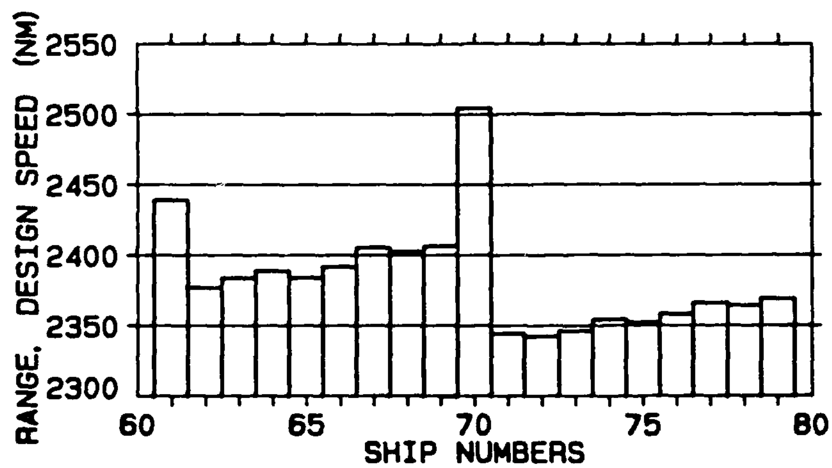

Figure D.2: Range at Design Speed, Ships 61 to 79

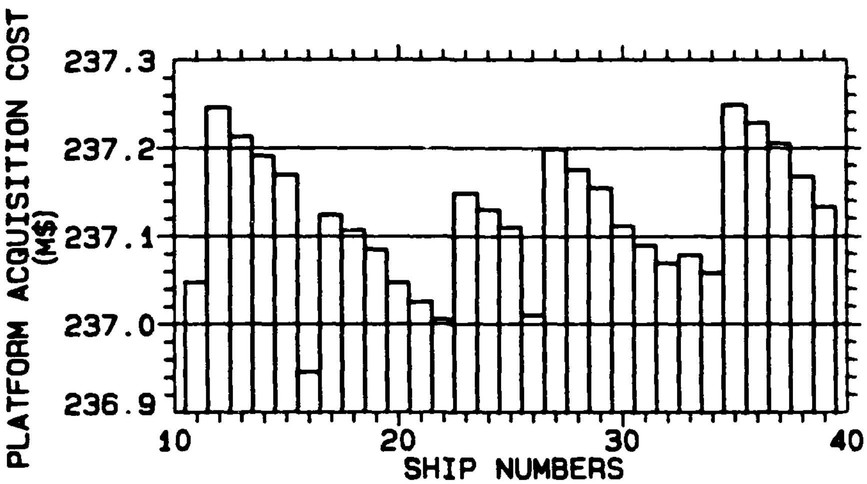

Figure D.3: Metacentric Height/Beam Ratio, Final-Run Ships

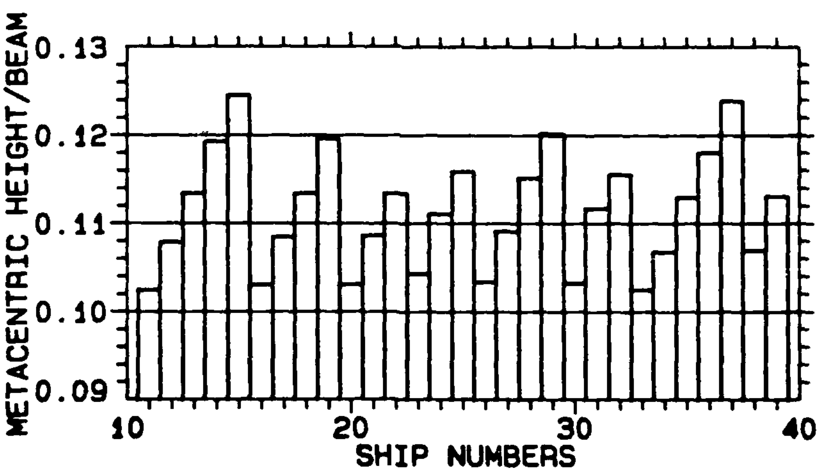

Figure D.4: Platform Acquisition Cost, Final-Run Ships

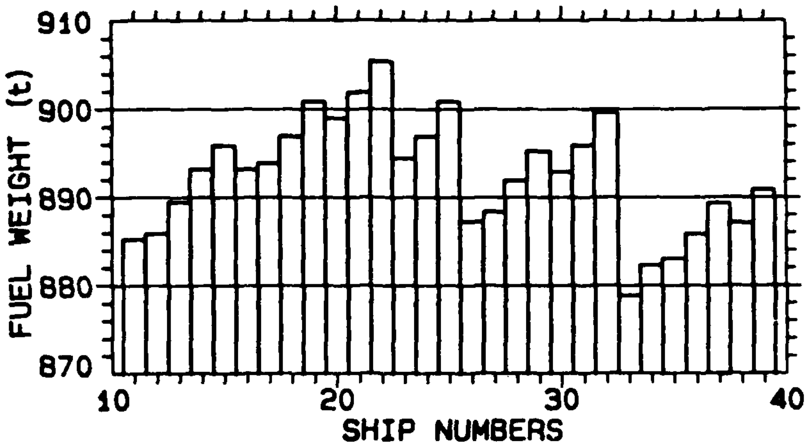

Figure D.5: Fuel Weight, Final-Run Ships

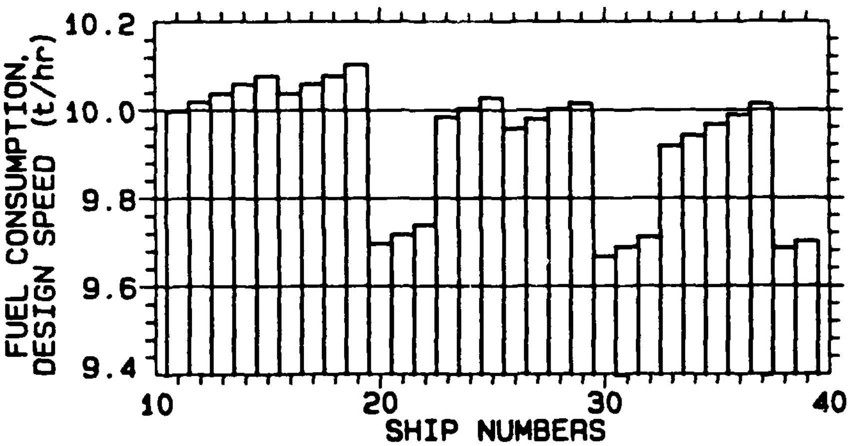

Figure D.6: Fuel Consumption at Design Speed, Final-Run Ships

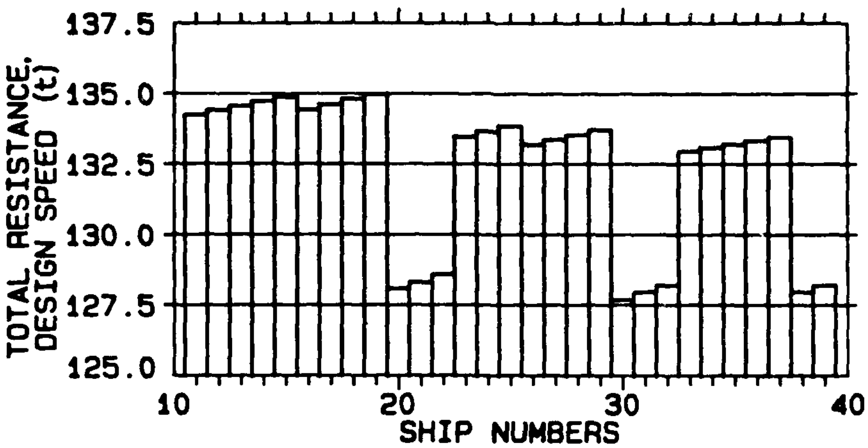

Figure D.7: Total Resistance at Design Speed, Final-Run Ships

Appendix E: FIVPOS Parameters

The FIVPOS parameters are listed in groups corresponding to the categories used on the FIVPOS parameter-access menu. Note that each parameter has a unique integer descriptor, and that the SHOP5 lineprinter notation is used for all parameter names.

	Primary Input	
1	DISP	Displacement
2	CrM	Length/Displacement Ratio, Ⓜ
3	Cp	Prismatic Coefficient
4	Cb	Block Coefficient
5	B/T	Beam/Draft Ratio
	Dimensions and Complement	
6	L	Length
7	B	Beam
8	T	Draft
9	D	Hull Depth
10	S	Wetted Surface
11	Vtotal	Total Enclosed Volume
12	Vsuper	Superstructure Volume
13	Vhull	Hull Volume
14	VOL	Displaced Volume
15	N	Complement
	Geometric Ratios and Coefficients	
16	L/B	Length/Beam Ratio
17	L/T	Length/Draft Ratio
18	L/D	Length/Hull Depth Ratio
19	Cw	Waterplane Coefficient
20	Cm	Midship Coefficient
21	DLR	Displacement/Length Ratio
	Cost	
22	P.A. $	Platform Acquisition Cost (lead ship)
23	$/DISP	P.A. Cost/Displacement
24	$/Vtotal	P.A. Cost/Total Enclosed Volume
25	$/Wcombat	P.A. Cost/Combat Systems Weight
26	$/Vcombat	P.A. Cost/Combat Systems Volume

Range

27	R(Vd)	Range at Design Speed
28	R(Vc)	Range at Cruise Speed
29	R(Ve)	Range at Endurance Speed
30	R(M)	Mission Range
31	R(Vd)/Wf	Range at Design Speed/Fuel Weight
32	R(Vc)/Wf	Range at Cruise Speed/Fuel Weight
33	R(Ve)/Wf	Range at Endurance Speed/Fuel Weight
34	R(M)/Wf	Mission Range/Fuel Weight

Weight Components

35	W1	Structure Weight
36	W2	Propulsion System Weight
37	W3	Electrical Systems Weight
38	W5	Auxiliary Systems Weight
39	W6	Outfit and Furnishing Weight
40	Wd	Disposable Loads Weight
41	Wf	Fuel Weight
42	Wcombat	Combat Systems Weight

Volume Components

43	Vm	Machinery Volume
44	Vn	Personnel Volume
45	Vo	Outfit and Systems Volume
46	Vf	Fuel Volume
47	Vcombat	Combat Systems Volume

Stability

48	GM	Metacentric Height
49	GM/B	Metacentric Height/Beam
50	GMf	Fluid Metacentric Height
51	GMf/B	Fluid Metacentric Height/Beam
52	KG	Vertical Centre of Gravity
53	KG/D	Vertical Centre of Gravity/Hull Depth
54	KG/KGmax	KG/maximum KG for Damaged Stability
55	Tau	Natural Roll Period (unappended)

Seakeeping

56	`Nwet`	Number of Deck Wetnesses
57	`Accn`	RMS Vertical Acceleration/g at Station 4
58	`Fslam`	Slam Force/Displacement
59	`S(Eff)`	Crew Seakeeping Effectiveness

Resistance and Propulsion

60	`Rt(Vd)`	Total Resistance, Design Speed
61	`Rt(Vc)`	Total Resistance, Cruise Speed
62	`Rt(Ve)`	Total Resistance, Endurance Speed
63	`OPC(Vd)`	Overall Propulsive Coefficient, Design Speed
64	`OPC(Vc)`	Overall Propulsive Coefficient, Cruise Speed
65	`OPC(Ve)`	Overall Propulsive Coefficient, Endurance Speed
66	`FC(Vd)`	Fuel Consumption, Design Speed
67	`FC(Vc)`	Fuel Consumption, Cruise Speed
68	`FC(Ve)`	Fuel Consumption, Endurance Speed
69	`Pins`	Total Installed Power
70	`Pmain`	Installed Power of Main Engines
71	`Pcruise`	Installed Power of Cruise Engines
72	`Vm/Pins`	Machinery Volume/Total Installed Power
73	`Vmax(w)`	Maximum Speed in Waves (limited by Pins only)
74	`e`	Transport Effectiveness
75	`SP`	Specific Power

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The SHOP5 System is a computer-aided ship design tool for monohull frigate and destroyer Concept Exploration. Its primary application is to initialize the new-ship design process by determining the ship size, hull form and major systems best suited for the design requirements. Other uses include evaluating new technologies and performing specific parametric studies. The SHOP5 System incorporates three major FORTRAN programs in a closed-loop system; program FIVPRE for defining and modifying ship descriptions and design requirements, program SHOP5 for computing ship characteristics, and program FIVPOS for examining design candidates using computer graphics. Design calculations include sea-keeping in head seas, resistance, powering and range in calm water and in waves, propulsion and electrical system modeling, distribution of weight and volume components, preliminary intact and damaged stability analysis, and platform acquisition cost. Platform feasibility is assessed by user-definable design criteria which define goals for performance and capability. The SHOP5 ship description and design methodology are sufficiently flexible to define and analyse a wide variety of ship geometries, systems and missions. Most input parameters have pre-programmed, default values representative of contemporary NATO practice and a variety of internal methods are available for many design calculations. All default values and most calculations can be modified or replaced by user-supplied input.

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